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Sewage Research

Gas Production from Screenings at Milwaukee, Wisconsin[1]

By Willem Rudolfs[2] and H. M. Heisig[3]

Introduction

In a previous paper[3] results were presented on the digestion of fine screenings at the Milwaukee, Wisconsin, sewage disposal plant. The experiments had been made on a semi-plant scale, but due to the type of apparatus available and the construction of the tank no accurate gas measurements could be made. Since then the large digestion tanks described by Townsend[5] have been in operation and in addition to a number of chemical analyses, gas production was accurately measured and the composition of the gas determined.

General Description of Plant

For a detailed account of the plant the reader must be referred to Townsend's[5] paper. The general features of the digestion plant comprise four digestion chambers, each 18 feet square with a total depth of 20 feet 9 inches. The tanks are covered with steel plate decks or tops with gas domes in the center. Each tank is equipped with water-sealed overflow boxes, serving as drains and emergency safety valves. On the outside walls of each tank are three draw-off pipes for drainage. Cross-connected piping is installed for recirculation of the contents of the tanks.

A scum rack was built and provision was made for recirculating digested sludge for the purpose of breaking down and submerging floating scum. Later a scum saturator was installed in the dome to permit circulation of the liquid to keep the scum and floating material wet. Individual gasometers take care of gas pressure during the charging periods, gas meters register the volumes of gas produced. Gas-fired hot water boilers with automatic control mechansims are used. The hot water is circulated by a motor-driven pump through black iron pipe arranged upon the four sides of each sloping bottom in the form of U's. The temperature of the several units may be varied as desired. The tanks are housed in a heated building.

The charging of the tank with raw screenings is accomplished with pneu-

[1] *Journal Series Paper of the New Jersey Agricultural Experiment Station, Department of Sewage Disposal.*

[2] *Chief, Department of Sewage Disposal.*

[3] *Research Chemist, Milwaukee Sewerage Commission.*

matic ejectors. The ejectors are operated in such a way that a screenings seal in the piping insures against the admission of air and the loss of gas from the various units. The ejectors are mounted on scales which record accurately the weight of the material charged to the tanks.

Fifteen glass-covered sludge drying beds are located immediately adjacent to the digestion tanks.

Operation of Plant

For the purpose of starting the digestion process several tank cars of digested sludge were imported from the separate sludge digestion plant at Antigo, Wisconsin. This seed material was divided equally among the four tanks and the charging of fine screenings was begun. The four units were operated at different temperatures and under varied conditions. The unit (No. 1) with which this paper deals was held at a temperature of 85° F. Special emphasis has been given to gas production.

This unit was seeded with 14,219 gallons of material with the following composition: Total solids, 11.24%; ash, 61.9%; nitrogen as NH_3, 2.5%; pH, 8.1; temperature at beginning, 61° F.

Calculated: Total dry solids, 13,180 pounds; total volatile matter, 5000 pounds.

The amount of dry screenings to be added was calculated, and the charges were increased gradually as conditions warranted. This procedure eliminated the danger of overloading the tank.

The tank was put into operation July 18, 1928, with the introduction of a small quantity of screenings. During the next fourteen days three more charges were added. Beginning August 1, daily additions were made. Gas measurements were not begun until August 28, as the tank was allowed to remain open in order to observe the activity and the behavior of the material charged. From observations the amount of gas produced during the month of August was comparatively small, due to low temperature and the small amount of screenings added.

The temperature of this unit at the beginning of operations and for the first several weeks varied between 61–68° F. Heating equipment was completed and heat first applied to the tank contents on August 21. Shortly after the application of heat there was a noticeable increase in gas production. For the first several weeks and occasionally thereafter city gas was used to raise the temperature of the tank contents.

The temperature of the fine screenings charged over the period of this experiment varied between a maximum of 70° F. during the summer months and a minimum of 44° F. during the winter months.

Difficulties

Considerable difficulty was encountered at the beginning of operation in circulating the digested sludge, because of the inability of the pumps to

handle material of this character with a low head of liquid in the tank. This difficulty was overcome as soon as the tank was filled.

Practically all of the fresh screenings charged rose to the top of the tank and formed a heavy blanket which was practically impervious to the gases produced. This blanket varied in thickness (after about two months of regular charging), from 4 to 6 feet at the point of charging and from $1^1/_2$ to $2^1/_2$ feet at a point most distant from the inlet. The screenings blanket at the outset gave considerable trouble because one-quarter to one-half of the mass lay above the liquid level due undoubtedly to entrained gases and the fact that practically all of the gas was trapped under the blanket proper. Digestion proceeded very slowly in this dry upper layer, in fact so slowly that it was deemed necessary to install an apparatus (scum saturator) for the purpose of seeding and soaking the screenings blanket.

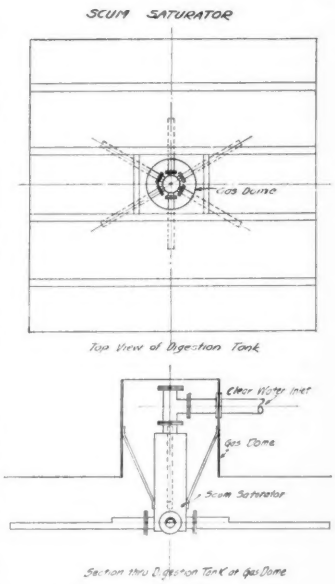

FIG. 1.—Scum Saturator.

For the first several months of charging the gas flow was very irregular and became more and more so as the screenings blanket increased in thickness. It was necessary for the gas to build up sufficient pressure to break through the blanket. At such times the flow of gas greatly increased, followed by a gradual decrease as the blanket became more impervious. As the screenings blanket increased in thickness the release of gas became more difficult and the pressure necessary for its release increased correspondingly. On several occasions the pressures became so high and the release so rapid that the material was blown out of the tanks through the water seal.

The scum rack, which had been installed for the purpose of keeping the scum submerged, failed to function. The scum for which the scum rack was intended is entirely different from the type of buoyant material found at the top of the tank as a screenings blanket.

Fortunately the scum rack installed in the tank had very wide openings and in no way interfered with the collection of gas. It is quite apparent that scum racks are of no value in the digestion of screenings.

Recirculation of digested sludge in conjunction with the scum rack failed to break down the screenings blanket, and it was necessary to resort to other means better adapted to the particular condition. With this idea

in mind a saturator was developed (Figure 1) and installed in January, 1929. The saturator consists of a central large diameter pipe connected to the draw-off pipes at the side of the tank. This central pipe is in a vertical position in the gas dome. From the bottom of this well there are six pipes, equally spaced, radiating out over the surface. Two of the horizontal pipes are about 4 feet long and saturate the inner circle, the others are from 6 to 7 feet in length and saturate the outer area. These pipes have been split so that they resemble a trough, and they overflow throughout their length.

The saturator is operated each day for about one hour. Upon operating the saturator it was noted that during the period of saturation there was an increase in the rate of release of gas. For the first several days gas accumulated between saturator operations. After several weeks of saturator operation the flow of gas became uniform throughout the day. No difficulty has since been experienced in the collection of gas.

At the beginning of the experiment the screenings mass (particularly that portion which was not submerged) was greenish yellow in color; this color was retained even after the experiment was well under way. The submerged portion, however, became darker in color and finally black. Some time after the installation of the saturator the blanket became a soggy mass black in color. Due to the release of entrained and trapped gases the blanket gradually submerged until only a very thin layer rose above the liquid level.

Material and Methods

It is estimated by Townsend[5] that the fine screens in use at Milwaukee retain about 12 cubic feet of fine screenings per million gallons of sewage. This means for the average flow of 100 million gallons daily approximately 1200 cubic feet of fine screenings. During the experimental period only a part of the total screenings was treated.

Total solids, ash of solids, ammonia and grease content determinations were made on the raw screenings as charged. The same analyses were made on the materials withdrawn, in addition to biochemical oxygen demand and pH determinations. In addition to the weighing of all the materials added and the metering of the gas, the composition of the gas was determined regularly. These analyses comprised: Carbon dioxide, carbon monoxide, oxygen, hydrogen, methane, illuminants; the remainder was considered to be nitrogen.

RESULTS

The results on operation here presented comprise the periods between July 18, 1928, and March 30, 1929, and for gas production the period between August 28, 1928, and March 30, 1929, or a total of 214 days.

The temperature record is graphically shown in Figure 2, together with the weekly averages of pounds of dry solids and weekly averages of total gas production. During the first six weeks the temperature was increased from 61° to 97° F. The reason for this high temperature was due to changes in experimentation. After this peak was reached the temperature was reduced. The average temperature for the whole period was 84° F.

For the first few weeks the charging was done at irregular intervals for fear of overloading the tanks. By the first of August the material in the tanks became rather active (apparent from observed gasification) and chargings were made every day. They were gradually increased until at the end of the month the calculated charges were exceeded.

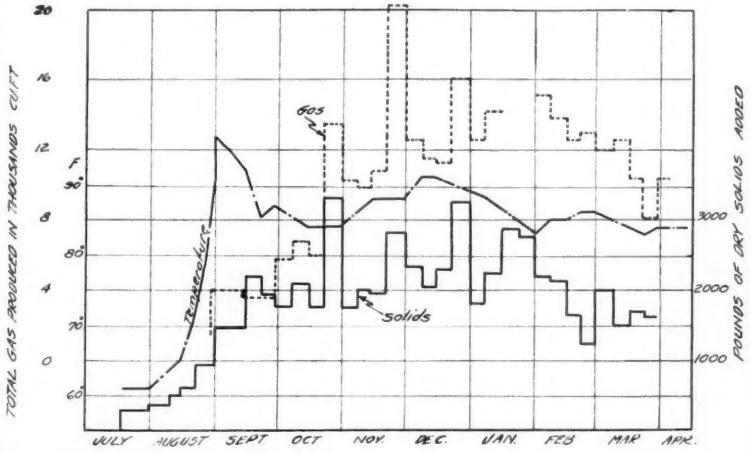

FIG. 2.—Changes in Temperature, Solids Added and Gas Production.

It was deemed advisable at the beginning of operations to leave the tank open so that observations could be made of the digesting material and to make the necessary tests on the pumping and recirculation equipment. On August 27, 1928, the tank was finally closed and gas measurements begun the next day. Not until shortly before closing the tank was the heating system started at full rate.

From Figure 2 it may be seen that the total gas production fluctuated directly with the fluctuations in the charges, although the increases and decreases in gas production were not proportional to the increases and decreases in total material added. It is obvious that the apparent relation between additions of solids and gas production is misleading since it takes some time before the material added on a given day produces gas. The digestion schedule was assumed to be 30–32 days. Plotted comparisons of

data showing the relation between solids additions and gas production for different periods of time (namely, 1, 2, 3 and 4 weeks) indicated that the peak of gas production for any given charge of material occurred between the third and fourth week after introduction. The calculated results of an elapsed period of 24 days, before maximum gas production occurred from any given amount added, are graphically represented in Figure 3. It will be noted that there is an apparently close agreement. It is evident, therefore, that the first peak in gas production in Figure 2 is due to accumulated material, the second peak to the increased load upon the tank, the third peak to the second group of increased batches, and so on.

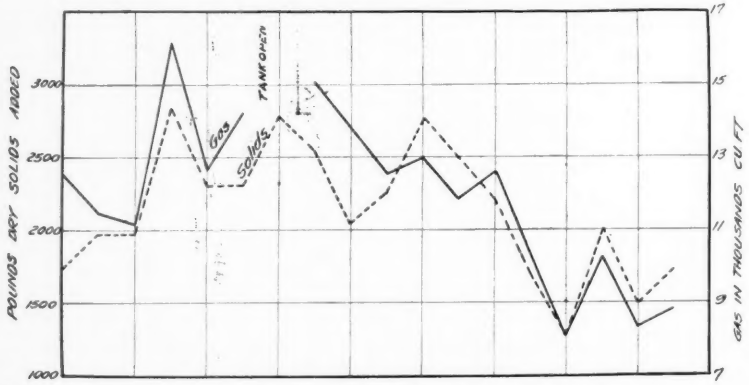

FIG. 3.—Relation between Solids Added and Gas Produced (Gas Produced 24 Days after Introduction of Solids).

The apparent relation between gas production and solids additions is, however, by no means proportional. There are considerable fluctuations in the daily gas production per pound of dry material as indicated by the plotted results in Figure 4. The daily gas production per pound dry solids added shows a gradual increase during the first two months, followed by a drop and again followed by a rise, until at the beginning of December somewhat of an equilibrium was established. In the middle of January the scum saturator was installed in this tank and the result was felt during the second part of February, after the material had been thoroughly soaked. This period was followed by a decrease in gas production, until finally by the middle of March the equilibrium was again established as indicated by the uniform gas production per pound of screenings added. It is evident, therefore, that the statement often made, that "gas production for some unknown reason fluctuates from day to day," is correct only in so far as the physical characteristics of the treated materials or equipment are concerned. If the materials are kept in such a condition that biological activities can

continue unhampered and the mechanical equipment is such that gas is released at a uniform rate, then gas production per given quantity of organic matter remains fairly constant. As soon as larger quantities of solids are added the gas production increases in proportion.

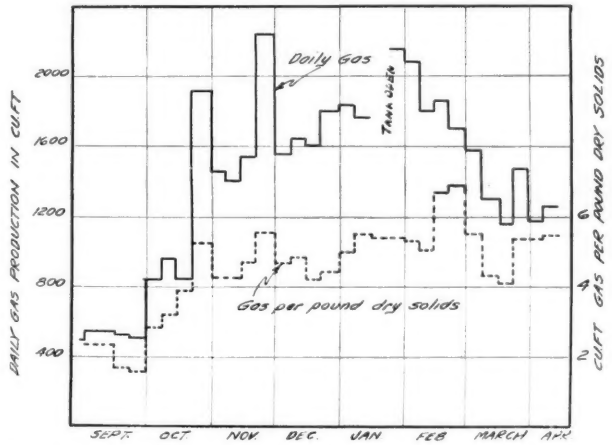

FIG. 4.—Daily Fluctuations in Gas Production per Pound of Dry Solids Added.

Composition of Gas

The fluctuations in composition of gas are shown in Figure 5. The CO_2 content of the gas is high in comparison with the CO_2 content of gas produced from sewage solids. Consequently the percentage of combustible gases is low.

Attention is drawn to the comparatively high O_2 content of the gas, which would indicate that air is entering the tank with the charged material. Repeated checking of the analyses indicates that the oxygen is present in the gas when drawn for analysis. The persistent presence of O_2 explains the rather high nitrogen content of the gas, which averaged 11.0 per cent. Naturally, the presence of air affects the percentage of combustible gases and would explain in part the lower values. However, this is only part of the cause. The real reason probably lies in the composition of the screenings. Sewage solids have on an average about 5 per cent nitrogen, expressed as ammonia, and about 30 per cent carbon, or a carbon to nitrogen ratio of approximately 6 : 1. The carbon content of fine screenings is undoubtedly higher than that of sewage solids and the nitrogen content at least 30 per cent lower. The carbon content of fine screenings collected at Plainfield, N. J., is considerably higher than that of the fresh sewage

solids, but even assuming that the carbon content of fine screenings is the same as of fresh solids, the carbon–nitrogen ratio is considerably widened, namely, from 6 : 1 to 9.2 : 1.

Carbonaceous substances produce large quantities of CO_2 as end-products. This has been repeatedly shown in the New Jersey Sewage Laboratory[2] in the studies of the digestion of pure substances and also for mixed vegetable materials. It would seem therefore, that the heat value of the gas from screenings will always be lower than that of gas from domestic sewage solids, unless means are found to modify artificially the digestion processes.

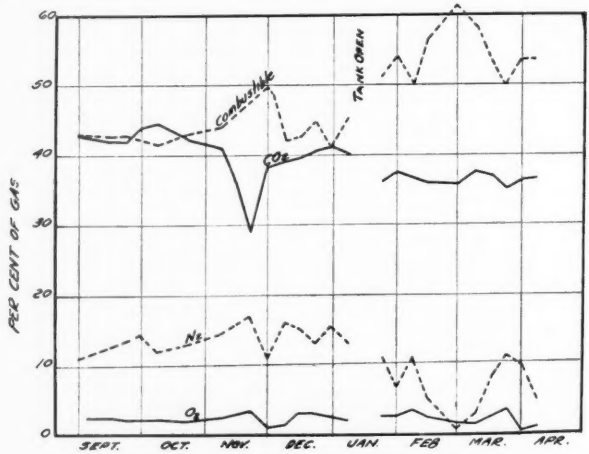

FIG. 5.—Changes in Composition of Gas Evolved.

Solids, Ash and Ammonia Content

It is of interest to note that the moisture content of the screenings is comparatively constant. Although determinations of the moisture and ash contents of the solids were made daily, excepting Sundays and holidays, only the weekly averages have been plotted and are presented in Figure 6. Contrary to expectations the solids content of the screenings increased gradually during the fall until the maximum concentration was reached in December, thereafter slowly decreasing again.

The percentage ash of the screenings remained fairly constant during the late summer, fall and early winter, but in February the ash content began to increase rapidly. It is a well-known fact that during the spring thaws and the rainy season the ash content of activated sludge increases materially. This increase is due to the finely divided inorganic material washed from the streets and carried to the plant. The increase in ash content of

both screenings and activated sludge occurred at about the same time. It might therefore be assumed that the cause of these increases was the same in both cases. However, the nitrogen value of the screenings remained practically constant throughout the test period, the average being 3.24 per cent. The nitrogen value of activated sludge varies indirectly as the ash content. It is quite apparent that the high ash content of the screenings was due to a change in the character of the material rather than to the dilution of the screenings with street washings.

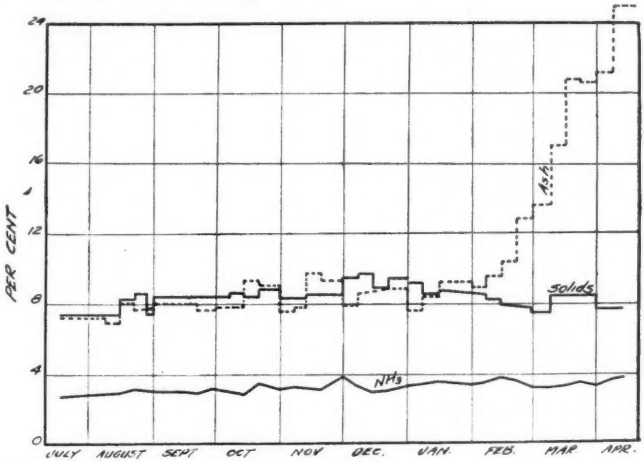

FIG. 6.—Variations in Percentages of Solids, Ash and Ammonia of Fine Screenings.

Material Withdrawn

During the entire period under discussion no ripe sludge, other than for samples, was withdrawn. Beginning October, 1928, supernatant liquid only was displaced after the tank became full. The liquid contained low concentration of total solids, varying between 0.12 and 0.41 per cent, with an average of 0.26 indicating its clearness.

The ash content of the solids in the sludge withdrawn for analysis varied between 41.15 and 56.0 per cent, with an average of 47.0 per cent. If it is remembered that the average ash content of the charged screenings was 10.1 per cent and that the ash content of the solids in the supernatant liquid in digestion tanks is not higher than in the sludge, these figures would indicate a quite remarkable increase in the percentage of ash, or in other words, a great reduction in volatile matter.

The biochemical oxygen demand of the sludge samples drawn varied between 210 and 1590 p. p. m. with an average of 780 p. p. m.

The solids content of the sludge samples varied considerably, namely, between 3.00 and 9.59 per cent, disregarding the solids content of the samples drawn during the first six weeks, when the sludge concentration was higher. Sludge drawn after the close of the period under discussion had a solids content of about 6.25 per cent.

The ammonia content of the ripe sludge drawn for analysis varied between 2.43 and 3.32 per cent with an average over the period of 2.96 per cent. Comparing these figures with the average figures for the ammonia content of the screenings added, it would appear that probably between 10 and 15 per cent of the ammonia was lost during the digestion period.

DISCUSSION

During the period August 29, 1928, to March 30, 1929, a total of 58,845 pounds dry screenings were added to this tank, equivalent to 728,460 pounds wet screenings. The average daily weight of wet screenings added was nearly 3400 pounds. Beginning with small quantities it was intended to increase the charges after definite periods until a maximum load was reached. During the time of the experiment these increases in charges were not made in accordance with the original plan, but changed so that comparisons could be made with the three other tanks, which were treated differently. For this reason the maximum load to be handled by the tank has not been determined as yet.

The moisture content of the charged screenings varied but little, as shown by the minimum, maximum and average results given in Table I. It is of interest to note that an average pH value of 8.0 obtained for the whole period. No attempt was made to control the reaction. The original ripe sludge used for seeding had a pH value of 8.1. The pH value of the withdrawn sludge and supernatant liquid dropped but slightly to a minimum, for a short period, of 7.6. This comparatively high pH value was maintained in spite of the comparatively low nitrogen content of the screenings. This fact would indicate that the maximum allowable dosage has by no means been reached. The B. O. D. values obtained on regularly made determinations indicate similar conclusions.

TABLE I

ANALYSES OF SCREENINGS ADDED

	Minimum	Maximum	Average
Solids, per cent	7.30	9.70	8.52
Ash, per cent	7.60	20.80	10.10
Ammonia, per cent	2.66	3.84	3.24
pH of tank contents	7.6	8.3	8.0
Temperature, ° F., of tank contents	61	97	84

The total recorded gas production during the 214-day period was 300,920 cu. ft. or an average 1406 cu. ft. per day. This recorded volume does

not represent all the gas produced since the tank was left open during the first six weeks, and was opened on several occasions for inspection and had to be open for a period of ten days when the scum saturator was installed. The total quantity of dry solids added amounted to 58,843 pounds. Disregarding the loss of gas and the fact that during the last month of the experiment screenings were introduced daily, which would tend to decrease production, the amount of gas produced per pound of dry solids amounted to 5.11 cubic feet. Assuming that all fresh screenings introduced had completed maximum gasification in 30 days, half of the quantities introduced during the last 30 days could be assumed to be complete, and the other half as having given no gas at all. Thus 15 days of screenings additions during the last 30 days, plus the 10 days gas lost during installation of the scum saturator, amounting to a minimum of 25 days, should be taken into account. The total duration of the experiment was 214 days with a loss of at least 25 days' production of gas. If this correction be applied the results indicate production of 5.7 cubic feet of gas per pound of dry screenings.

Laboratory experiments on the digestion of fine screenings[4] showed a gas production from seeded fine screenings after a digestion period of 30 days of 402 cc. gas per gram volatile matter originally added and 412 cc. after digestion for 40 days. Gas production per gram of volatile matter added as screenings in the large scale experiments described herein amounted to 391 cc. or very nearly the same quantity as was obtained under strictly controlled laboratory conditions. It would seem, therefore, that no great increase in the quantity of gas can be expected unless ways and means are found to decompose the screenings further than is at present economically possible with the methods employed.

The composition of the gas determines its heat value. A summary of the gas analyses is given in Table II. As was pointed out above the large quantity of oxygen present indicates that some air was mixed with the gases. This lowered the percentage of combustible gases and consequently the

TABLE II

COMPOSITION OF GAS PRODUCED

Component	Per Cent		
	Minimum	Maximum	Average
Carbon dioxide	29.0	44.6	39.1
Carbon monoxide	0.3	3.2	2.3
Illuminating gas	0.6	2.8	1.2
Methane	34.9	58.0	44.1
Hydrogen	0.0	3.3	...
Total combustible	36.3	62.0	47.8
Oxygen	0.2	3.6	2.3
Nitrogen*	0.6	26.2	11.0

* Determined by difference.

heat value. The average carbon dioxide was about double that found in gas produced from fresh solids, and nearly 10 per cent greater than found in the laboratory experiment. Figure 5, giving the changes in the constituents of the gas evolved, shows that during the second half of the experiment the percentages of CO_2 were smaller than during the first half, with corresponding increases in the percentages of combustible gases. It is possible, therefore, that the average heat value of the gas would be considerably higher after continuous operation than is indicated in the figures.

Economic Importance of Gas Collection

Engineers and municipal authorities are always interested in the possibility of decreasing the cost of construction and operation of sewage plants.

While it is not the purpose of this paper to discuss the question of reduction of costs in digestion of screenings by utilization of the gases produced, still it might be well at this time to compare some of the figures obtained in this experiment with those presented by another experimenter, namely, Prüss,[1] in his recent work, "Advancement of Sewage Sludge Digestion." Prüss, following a discussion of the comparative costs of construction of unheated digestion tanks, in which the material is left quiescent, with tanks properly heated and mixed by sludge circulation, comes to the conclusion that under certain circumstances the value of the gas produced will be more than sufficient to defray all operation costs. He states that the net profit from a small disposal plant is 5.6 cents per capita per year. This figure is the net profit, the cost of operation plus 10 per cent of the construction costs for depreciation, interest and repairs having been deducted. The selling price of the gas produced was taken as $0.533 per 1000 cubic feet (8 pfennig per cubic meter). He further states that at large sewage disposal plants the excess of gas can be used for power in the operation of air blowers in connection with the activated sludge process and that this can be accomplished without cost and with a yearly surplus in addition. Prüss assumes a sewage temperature of 59° F., and a daily sludge production of 50 grams of dry solids per capita, with 60 to 65 per cent volatile matter. This gives, with a moisture content of 95 per cent, about one liter of sludge per capita per day. For the sake of comparison we might assume the same quantity of dry solids per capita and a similar ash content. (Domestic sewage solids have in this country about 75 per cent volatile matter, which decreases with the amounts of trade wastes received to 50 per cent or less.) From one liter of sludge (95 per cent moisture) Prüss expects to obtain a maximum of 20 liters of gas per capita per day, or 11.6 liters when the sludge is digested to a point ready for withdrawal. This he considers the quantity that can be economically expected. The maximum gas production would then be 400 cc. and the expected quantity 232 cc. per gram of dry solids. This would amount to 510–560

and 312–334 cc., respectively, per gram of volatile matter. These estimates are low, if anything. Gas evolution per gram of dry screenings at Milwaukee amounted to 356 cc. or 391 cc. per gram of volatile matter, which is considered about 20 to 25 per cent below the volume produced from domestic fresh solids.

Let us assume that in a sewage disposal plant treating the sewage from 10,000 people an amount of 50 grams of dry sludge per capita per day is retained. Assume further a gas production of 400 cc. per gram of dry solids = 400 × 50 = 20,000 cc. (this is one-third more than Prüss expects).

10,000 people produce 200,000 liters or about 7070 cubic feet daily.
Per year 7070 × 365 = 2,580,000 cubic feet.
Sell gas at 53.3 cents per 1,000 cubic foot = $1376

However, most of this gas is needed for raising the temperatures of the digesting materials. Calculations on heat values of gas and heat loss based upon small laboratory experiments, which check fairly well with results obtained at Antigo and Milwaukee show that, for raising the temperature to 70° F. from 75–80 per cent of the *total* gas produced is necessary unless the tanks are very well insulated; in order to raise the temperature to 80° F. when the above maximum gas production might be expected, 90 per cent or more of the gas produced is required for heating. If we assume that a surplus were available and the gas could be conveniently sold, and further assume that with the present methods we could have available a 25 per cent surplus, which is better than Prüss assumes, we would have only $369 available for operation, interest and repairs, to say nothing about secondary treatment processes. Not many operators could be found to run such a plant efficiently on a salary of $369 per year. Prüss felt apparently, that his calculations, even for German conditions, were somewhat optimistic and suggests therefore (and presents calculations) that the heating should be done by coal and the gas sold. It is very doubtful that there would be many instances in this country where such a procedure would be welcomed or even possible at the present time. It would seem, for the time at least, that the engineer must content himself with a reduction in original construction, operation and maintenance costs and not lay too great stress on the possibility of revenue from our sewage disposal systems.

SUMMARY

Large-scale experiments on digestion of fine screenings were made at Milwaukee, Wisconsin, Sewage Disposal Plant. The tank was seeded with ripe sludge from a separate sludge digestion tank. Difficulties in operation, consisting mainly of the formation of a thick, heavy blanket of floating material, were overcome by the installation of a scum saturator. The duration of the experiment reported upon was 214 days. A total quantity of

58,843 pounds dry screenings was added or nearly 3400 pounds wet material per day. The temperature in the tank averaged 84° F. Gas production amounted to 5.7 cubic feet per pound dry solids or 391 cc. per gram volatile matter treated. The composition of the gas produced differed from that evolving from digesting fresh sewage solids in that the CO_2 content was higher and the percentage of combustible gases lower. Curves show the fluctuations in gas production, composition of gas and composition of screenings added. A discussion on heat value and possible revenue from gas collection and marketing is included.

The authors are greatly indebted to Mr. D. E. Bloodgood, chemist, for the assistance given in conducting the experiment as well as collecting the chemical data.

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Determining the pH of Sewage Sludge by the Dilution Method*

BY F. R. MCCRUMB**

The digestion of sewage sludge occurs in two principal phases, generally designated as the putrid and the odorless phases. The first phase is characterized by the production of acid materials, foul odors and a sticky sludge poor in drainability; the second by the production of alkaline materials, tarry or earthy odors and a granular sludge, which tends to drain readily. The aim of efficient sewage treatment is to encourage the development of the second phase and inhibit the development of the first phase in so far as it is practically possible. It can readily be seen why a condition of acidity should be avoided.

In dealing with conditions where acidity and alkalinity are important, we may be interested in two factors, the total concentration of acid or alkali, or the active concentration. The former is a quantity factor entirely; the latter, an intensity factor. The three acids, hydrochloric, acetic, and boric, when dissolved in water, have the common property of splitting, or in the terms of the chemist, of dissociating to form hydrogen ions. The acidity of such solutions is due to these ions. All acids do not dissociate to the same extent in aqueous solution, consequently the concentration of hydrogen ions may depend more on the degree of dissociation than on the total amount of acid present. It is well known that there is a pronounced difference in the properties of solutions of the three acids just mentioned. A solution of hydrochloric acid is corrosive, a solution of acetic acid is frequently a part of our diet as vinegar, whereas we may employ a boric acid solution as an eye wash. This difference in degree of acidity is due to the fact that there is a tremendous variation in the extent to which these acids dissociate in water to produce hydrogen ions. For instance, solutions of the three having the same total concentrations in chemical equivalents, say 0.1 *N*, will vary roughly in hydrogen-ion concentration in the ratios, 15,000 : 200 : 1. The acid intensity of 0.1 *N* hydrochloric acid is therefore roughly 75 times that of acetic acid, and 15,000 times that of boric acid of the same normality.

A similar differentiation is true in the case of alkalies, with the exception that the important constituent of the solutions is the hydroxyl ion. No one would think of substituting a solution of caustic soda, soda ash or lime for one of baking soda, even if the total concentrations were chemically equivalent.

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It becomes necessary then to make use of an intensity scale of acidity and alkalinity, as well as a quantity scale. This intensity scale is known as the pH scale. A pH value of 7.0 represents exact neutrality, where the hydrogen and hydroxyl ions are present in extremely low but equal concentrations. Values below pH 7.0 denote active acidity, and the values decrease as the acidity increases. Values above pH 7.0 denote active alkalinity and the values increase as the alkalinity increases. Thus a solution at pH 6.0 will be more acid than one at pH 7.0, whereas a solution at pH 8.0 will be more alkaline than one at pH 7.0. If we take as examples the solutions previously mentioned in 0.1 *N* concentrations, we will find that in round numbers they have the following pH values:

TABLE I

APPROXIMATE pH VALUES OF VARIOUS ACIDS AND ALKALIES

Acids	pH Value	Alkalies	pH Value
Hydrochloric acid	1.0	Sodium bicarbonate	8.4
Acetic acid	2.9	Sodium carbonate	11.6
Boric acid	5.2	Sodium hydroxide	13.0

For practical purposes the pH scale can be employed and accurate measurements made without a knowledge of the theoretical derivation of the term. Those interested in knowing its theoretical significance can find a complete discussion in Clark's excellent book "The Determination of Hydrogen Ions," 1928, Williams and Wilkins, Baltimore, Maryland. A simplified explanation can be secured from the booklet, "The A B C of Hydrogen Ion Control," LaMotte Chemical Products Company, Baltimore, Maryland.

It has been demonstrated repeatedly in the field of bacteriology that the growth of microörganisms is markedly influenced by the pH of the medium.[1,2,3] By controlling the pH the growth of certain organisms can be accelerated and the growth of others retarded. Since the digestion of sewage sludge is essentially microbiological in character, the importance of pH control is obvious. Certain strains of microörganisms will digest sludge to produce results that meet our requirements; other strains will produce results that, according to our standards, are extremely unsatisfactory. Rudolfs[4] has studied the various factors that influence sludge digestion and found that the pH is one of the most important. If the putrid stage of digestion is in the ascendency, the pH may fall as low as 5.0. This stage is therefore frequently referred to as the acid phase. When digestion is proceeding as ordinarily desired, the pH will be near exact neutrality, pH 7.0, or even slightly above, pH 7.0 to 7.6. If the sludge is either too acid or too alkaline, digestion is very slow, offensive odors are given off, and foaming may occur. This is true whether the digestion takes place in Imhoff, septic or separate sludge digestion tanks. The reaction of digesting

material is closely connected with liquefaction and gasification of the material. When the pH is 7.3 liquefaction overbalances gasification. More methane gas is formed at a higher pH value. The formation of methane gas is so linked with satisfactory digestion, that the so-called alkaline phase has also frequently been referred to as the "methane stage."

Optimum digestion will occur over a relatively small pH range, which may vary slightly depending on conditions. Rudolfs[4] reports that the best pH range is between 7.3 and 7.6. Fair and Carlson[5] working with sludges from Brockton and Fitchburg, Mass., give pH 6.8 as the lower critical value for methane production, and pH 7.2 as being near the optimum. Hatfield[6] at Decatur, Ill., secures satisfactory digestion at pH 6.8 to 7.0 and foaming has occurred at a pH of 6.5.

Satisfactory working conditions may be attained by the use of lime whenever necessary[7] or better by maintaining the proper ratio of ripe sludge to fresh solids.[4] Large amounts of lime are somtimes necessary when a new plant is started, since little or no seeding material may be available.[8,9]

In view of the importance of pH control in sludge digestion, it is apparent that a satisfactory means for determining the pH is essential. There are two general methods in use, namely the potentiometric and the colorimetric.

In the potentiometric method, often called the electrometric, some type of electrode is placed in the sample under examination, and this combination is then joined in series by suitable connections with a standard cell, the potential of which is known. By means of a potentiometer or millivoltmeter the total potential of the circuit is determined and the potential of the electrode in the sample found by difference. In the absence of interfering factors this potential will vary with the pH of the solution in which the electrode has been placed. Knowing the potential and temperature it is possible to calculate the pH. Various kinds of electrodes are employed in pH work, but the quinhydrone type appears to be the most satisfactory for sewage. In this type a plain platinum or gold electrode is used in the presence of a small amount of an organic compound, quinhydrone. Such an electrode reaches equilibrium rapidly when no interfering substances are present.

The colorimetric method is based on the fact that a number of organic dyes are available which have variable colors depending on the pH of the solution in which they are placed. These are called indicators. For example, the indicator bromthymol blue is yellow at a pH of 6.0 or under, and blue at a pH of 7.6 or over. Between pH 6.0 and pH 7.6 the colors vary from yellow through green to blue. It is possible to prepare so-called "buffer" solutions containing mixtures of various salts that will maintain a constant pH. If such a series of mixtures is prepared so that they have pH values in definite intervals, say 0.2 pH, as 6.0, 6.2, 6.4, etc., and a definite amount of the indicator bromthymol blue is introduced, a series of

color standards is available. These standards may be placed in sealed ampoules of a convenient size. Such standards if properly prepared and standardized and accorded reasonable care, will maintain their original color for long periods of time. Standards being available, if the same concentration of indicator is now set up in the unknown sample, in a tube having the same diameter as the standard, this mixture can be compared with the standards and the pH of the unknown material determined. This is the basic procedure of the colorimetric method, regardless of the type of color standard employed. The color mixtures ("buffers") used for reference must always be standardized by means of an extremely accurate potentiometric method, the standard electrode being at present the hydrogen one, which is essentially a platinum electrode coated with platinum black and saturated with hydrogen gas at atmospheric pressure.

In choosing a method for determining the pH of sewage sludge, the nature of the sludges that may be encountered must be considered. Sewage sludge is a highly complex substance. In addition to the liquid portion, which may contain an appreciable amount of dissolved salts, there is considerable colloidally-dispersed matter, together with suspended solids. The color may be quite black in many cases. In addition, the gas content may be high and the loss of certain gases while determining the pH may invalidate the results.

Color and turbidity alone are not interfering factors in the potentiometric method, but suspended solids, even though finely divided, frequently lead to erroneous results by coming in contact with the electrode, and thus modifying the potential. Materials of a reducing nature also sometimes cause errors. In addition to these specific difficulties there is the added disadvantage that any potentiometric method requires fairly close supervision by one thoroughly familiar with the principle. Constant checking by means of standard buffer solutions should be practiced. Although suitable equipment for the quinhydrone electrode set-up is now available at a cost considerably below that of other potentiometric equipment, this is still far in excess of the cost of a reliable colorimetric outfit.

On first thought it might appear that a colorimetric method could not be applied to sludge because of the high turbidity and color so frequently encountered. However, there are several procedures that are ordinarily followed in order to obviate the difficulties due to these factors. The object is to decide which procedure will give the most reliable results. Not all the turbidity and color in a sample need be removed before a colorimetric determination can be made. If the comparator method is employed, it is only necessary that sufficient light penetrate the test portion so that the color of the indicator is distinguishable. The test portion containing the indicator is not compared directly with the standards, but the color of the standard is observed through a layer of the sample which contains no indi-

cator. The same thickness of liquid is maintained by placing a tube of distilled water in front of the test portion. This scheme can be illustrated as shown in Figure 1.

The letters B, A, C and E, D, F are used to designate the holes in the block; G is the colored or turbid sample being tested; I is the indicator and W is water. The combination GI is the test portion to which the indicator has been added. The combinations IW are the clear color standards. It will be noted that all three pairs of tubes contain the combination GIW, only the members are differently distributed.

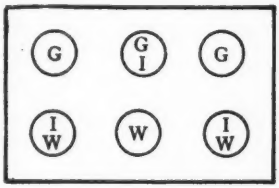

FIG. 1.

Excessive turbidity is frequently reduced by means of centrifuging or filtering. Efficient centrifuging removes most of the suspended matter and perhaps a little of the colloidal matter, but even then some samples are too turbid or too highly colored for a satisfactory determination. Filtration through coarse paper or glass wool is sometimes recommended. Such procedures may give accurate results in some cases, but there is great possibility of error when either method is employed. An important factor in determining the pH of sludge is the carbon dioxide content. During filtration the sample is always likely to lose carbon dioxide. This raises the pH in the test portion, and the determination may indicate a higher pH than actually exists in the sludge. In fact, the loss of carbon dioxide is probably one of the most prevalent sources of error in testing sludge and care should always be taken to avoid this loss, regardless of the method employed in determining the pH. Filtration through glass wool sometimes results in errors because of the fact that this material, due to its method of manufacture, is frequently coated with a thin layer of alkali, probably soda ash. This is dissolved by the sample during the filtration and raises the pH accordingly.

A third method of avoiding the difficulty due to excessive color and turbidity is to dilute the sludge with distilled water to a point where a satisfactory colorimetric reading can be made. On first thought one would expect that such a procedure would modify the pH and render a determination valueless. Dilution does, of course, change the total acidity or alkalinity, but it will be demonstrated by the data in this paper that moderate dilution with distilled water has an inappreciable effect on the pH of sewage sludge. The pH of a sludge is probably determined by the fact that certain constituents are present in definite ratios. Moderate dilution apparently does not modify these ratios to an appreciable extent, and the pH is thus changed only slightly. A material which tends to resist change in pH after this manner is said to possess buffer action, or to be buffered. The buffer action of sludge will also be demonstrated in another way.

Following the original method of Clark and Lubs,[2] it has become customary to employ color standards and test tubes having an internal diameter of about 16 millimeters. The indicators in concentrations varying from 0.02 to 0.04 per cent are added to standard buffer mixtures and to the unknown in the proportions of 0.5 cc. to 10 cc., giving a final concentration of 0.001 to 0.002 per cent. Any colorimetric procedure based on the use of so thick a layer of solution and so low a concentration of dye is apt to prove unsatisfactory for the liquor from sewage sludge. This is true regardless of the type of standards used, whether they are solutions or glass. In order that dilution need not be carried to extremes, other modifications of the colorimetric method are necessary for sludge.

Fischer,[10] working with Rudolfs at the New Jersey Sewage Laboratory, has advocated a method which is extremely satisfactory in determining the pH of sewage sludge. This method is similar in all respects to the one ordinarily used in industry, except that the color standards and test tubes employed are of smaller bore and the indicator solutions are of higher concentrations. This gives a more intense color and makes it possible to carry out a colorimetric determination when the turbidity and color are fairly high, where the ordinary colorimetric method would not be satisfactory. In addition, with the stronger indicator solutions, there is less chance of error, due to adsorption of the indicator by suspended matter and colloids.

FIG. 2.—LaMotte Sludge Testing Set.

The object of the investigation reported in this paper was to study the effect of dilution on the pH of sludge, in order to determine the degree of accuracy of the dilution method. A modification of the procedure advocated by Fischer was adopted as the colorimetric method. All results were checked by means of the quinhydrone electrode since, in most cases, it was possible by this method to determine the pH before any dilution was made. Thus it was possible to detect any change in pH due to dilution.

The colorimetric pH equipment used in the work reported in this paper is shown in Figure 2. It consists of three sets of color standards for the indicators, chlorphenol red (pH 5.2 to 6.8); bromthymol blue (6.0 to 7.6); and phenol red (6.8 to 8.4), in intervals of 0.2 pH, prepared in sealed ampoules of nonsoluble glass, the ampoules having an internal diameter of 10 mm.; test tubes having the

same diameter, and graduated to hold 5 cc.; indicator solutions having the concentrations, chlorphenol red, 0.08 per cent, bromthymol blue, 0.08 per cent and phenol red, 0.04 per cent; a pipette graduated to deliver 0.25 cc. for each indicator solution; a dilution tube, and a small comparator block fitted with a ground glass window to eliminate shadows. The indicator solutions were used in the proportion of 0.25 cc. of indicator to 5 cc. of sample, both in the preparation of standards and in the tests.

The potentiometric equipment employed consisted of a plain platinum foil electrode in the presence of quinhydrone, together with a saturated calomel cell, saturated potassium chloride bridge and a Leeds and Northrup hydrogen-ion potentiometer. The null point was determined by means of a Leeds and Northrup lamp-and-scale galvanometer. The potentiometer was balanced against a standard Eppley cell and the entire system was frequently checked against buffer mixtures of known pH.

At first distilled water that was practically free from carbon dioxide, having a pH of 6.8, was used to make the dilutions. It was found, however, that ordinary distilled water in equilibrium with the carbon dioxide of the air, pH 5.8, gave identical results, unless dilution was carried to a dangerous extreme. Since ordinary distilled water is usually more readily available it was decided that this investigation would have more practical value if it were used.

The general procedure followed was to introduce a definite volume of well-mixed sludge into a definite volume of distilled water. All transfers were made by means of special large bore pipettes. The diluted samples were well mixed and the pH determinations made immediately, both by the quinhydrone electrode and by the colorimetric method. The total time required to prepare each dilution and carry out the tests was never more than ten minutes and usually much less.

Ten samples of sludge were examined in all. These were of variable nature in that the state of digestion ranged from a very obnoxious sample, No. 8, to completely-digested sludges, such as sample No. 1. The total solids content ranged from 8.5 to 180 grams per liter. Some samples were obtained from the Back River plant in Baltimore. Several were from trade-waste treatment plants.

The results secured are given in detail in Table II.

While most of the data in the table are self-explanatory, some information should be given regarding the separate headings. The first column gives the number of the sample. The second column gives the total solids in grams per liter of sludge. Total solids were determined by heating a known volume of sludge, first on a water bath and then in an electric oven at 105° C., until the weight remained constant. The last six columns contain the data secured by determining the pH at the various dilutions. QH refers to the quinhydrone electrode, PR to phenol red, BTB to bromthymol blue,

and CPR to chlorphenol red, these being the indicators employed. A plus sign (+) indicates a reading above, a minus sign (−) a reading below the range of the indicator.

TABLE II

THE EFFECT OF DILUTION ON THE pH OF SEWAGE SLUDGES

Sample No.	Total Solids, g./l.	Method	pH on Dilution					
			No Dilution	Dilution 1:1	Dilution 1:4	Dilution 1:9	Dilution 1:19	Dilution 1:49
1	180	QH	...	...	7.47	7.46	7.47	7.40
		PR	...	...	...	...	7.4	7.4
		BTB	...	...	...	...	7.3	7.3
		CPR	...	...	...	...	6.8+	6.8+
2	80	QH	...	7.45	7.46	7.46	7.39	7.32
		PR	...	...	7.4	7.4	7.3	7.3
		BTB	...	...	7.4	7.4	7.3	7.3
		CPR	...	...	6.8+	6.8+	6.8+	6.8+
3	24	QH	7.32	7.32	7.39	7.39	7.25	7.14
		PR	...	7.3	7.3	7.3	7.3	7.2
		BTB	...	7.3	7.3	7.3	7.3	7.1
		CPR	...	6.8+	6.8+	6.8+	6.8+	6.8+
4	21	QH	7.52	7.54	7.54	7.47	7.26	6.82
		PR	...	7.5	7.5	7.5	7.2	6.9
		BTB	...	7.5	7.45	7.45	7.15	6.9
		CPR	...	6.8+	6.8+	6.8+	6.8+	6.8+
5	37	QH	7.02	7.00	6.98	6.98	6.85	6.77
		PR	...	7.0	7.0	7.0	6.9	6.8
		BTB	...	7.0	7.0	7.0	6.9	6.8
		CPR	...	6.8+	6.8+	6.8+	6.8	6.8
6	69	QH	6.87	6.84	6.84	6.74	6.69	6.49
		PR	6.8	6.8	6.8	6.8	6.8−	6.8−
		BTB	6.8	6.8	6.8	6.8	6.7	6.5
		CPR	6.8	6.8	6.8	6.8	6.7	6.5
7	67	QH	6.80	6.90	6.88	6.86	6.84	6.71
		PR	6.8	6.9	6.8	6.8	6.8	6.8−
		BTB	6.8	7.0	6.85	6.85	6.8	6.7
		CPR	6.8+	6.8+	6.8+	6.8+	6.8+	6.6
8	46	QH	6.25	6.30	6.37	6.43	6.49	6.52
		PR	6.8−	6.8−	6.8−	6.8−	6.8−	6.8−
		BTB	6.2	6.3	6.3	6.4	6.45	6.5
		CPR	6.2	6.4	6.4	6.4	6.5	6.5
9	8.5	QH	6.19	6.29	6.33	6.35	6.35	6.36
		PR	6.8−	6.8−	6.8−	6.8−	6.8−	6.8−
		BTB	6.2	6.3	6.3	6.4	6.4	6.4
		CPR	6.2	6.3	6.3	6.3	6.3	6.3
10	32	QH	6.95	6.95	6.88	6.80	6.66	6.56
		PR	6.9	6.9	6.9	6.8	6.8−	6.8−
		BTB	6.9	6.9	6.9	6.8	6.7	6.6
		CPR	6.8+	6.8+	6.8+	6.8	6.6	6.5

It will be seen that there was good agreement in the results by both methods, as well as by the different indicators. In all cases the agreement was

within the limit of sensitivity of the colorimetric method, namely 0.1 pH. A dash in the table indicates that the sample was too thick or turbid to test. The effect of dilution is further illustrated by the curves on Plate I.

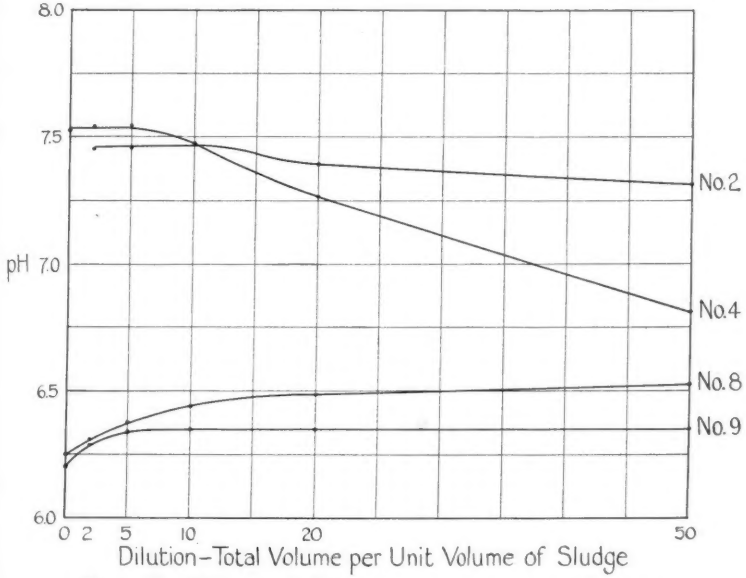

Plate I. Effect of Dilution on the pH of Sludge

When the specially designed colorimetric equipment was used it was possible to make a test without dilution on five of the ten samples. The sample was well mixed and allowed to stand for a short time. Sufficient of the liquid portion could then be pipetted off to make a determination. Nine of the ten samples could be tested at a dilution of 1:4 and in no case did the average colorimetric reading vary from the pH of the undiluted material by more than 0.1 pH, which is the average limit of sensitivity of the method. At a dilution of 1:9 the variation exceeded this limit in three cases, samples No. 8, 9 and 10, where the variation of the average colorimetric reading from the pH of the undiluted sludge was 0.2, 0.15 and 0.15 pH, respectively. In only one case, No. 1, was it necessary to exceed the dilution 1:9. This sludge was drawn from the bottom of a tank and had an unusually high content of total solids. In the case of this sample and also No. 2, dilution was carried much further, in order to determine the effect. The results secured are given in Table III. Only the averages of the colorimetric readings made with different indicators are given. Col. stands for colorimetric, QH for the quinhydrone method.

TABLE III

THE EFFECT OF DILUTION ON THE pH OF SOME HEAVY SLUDGES

Sample No.	Method	Diln. 1:4	Diln. 1:9	Diln. 1:14	Diln. 1:19	Diln. 1:39	Diln. 1:59	Diln. 1:79	Diln. 1:99	Diln. 1:149
1	QH	7.47	7.46	No	7.47	7.40	No	No	7.27	7.11
	Col.	..	..	tests	7.4	7.3	tests	tests	7.3	7.1
2	QH	7.46	7.46	7.39	7.32	7.29	7.20	6.98	6.90	No
	Col.	7.4	7.4	7.3	7.3	7.3	7.2	7.0	6.9	tests

To illustrate further the buffer capacity, or resistance to change in pH which sludge may possess, a series of tests was made in which 10 cc. of sludge, No. 1, was treated with variable quantities of either 0.2 *N* hydrochloric acid or 0.2 *N* sodium hydroxide. Each mixture was then diluted to 200 cc. and the pH determined as in the previous tests. Table IV gives the results secured.

TABLE IV

CHANGE IN pH ON TITRATION OF SLUDGES

0.2 *N* HCl Added, Cc.	0.2 *N* NaOH Added, Cc.	pH Quinhydrone Electrode	pH Colorimetric
6.0		5.29	5.3
5.0		5.90	5.8
4.0		6.02	6.0
2.0		6.51	6.5
1.0		6.98	6.9
0.5		6.98	6.9
0.25		7.29	7.3
0.00	0.00	7.47	7.4
	0.10	7.47	7.4
	0.25	7.66	7.6
	0.50	8.00	8.0
	1.00	8.34	8.3
	2.00	8.78	8.7
	4.00		9.4

The last two colorimetric determinations were made with thymol blue, an indicator not often required in sewage work since such high values are rarely encountered. No quinhydrone electrode measurements were made above pH 9.0, since this electrode is not particularly satisfactory in solutions so alkaline.

The curves on Plate II serve to illustrate the difference between titrating a sewage sludge which is quite highly buffered and titrating a solution of pure base or acid where the buffer effect is negligible. The acid-base curve is quite steep since it requires only a minute amount of acid to change the pH from 8.4 to 4.0, whereas the titration curve for the sludge has a very gradual slope. This illustrates the resistance to change in pH or the buffer action. It is this buffer action that permits dilution with distilled water without appreciable change in the pH as determined.

It was stated previously that care should be exercised when filtration is practised. The possibility of errors is shown by the results secured in several tests. When sample No. 5 was filtered through untreated glass wool, the pH of the undiluted filtrate was 8.9. Such a result would, of course, excite suspicion in practice. If, however, a smaller change were to occur the result might be accepted as an accurate value. Alkaline glass wool can be improved by boiling or soaking in dilute acid followed by thorough rinsing with distilled water.

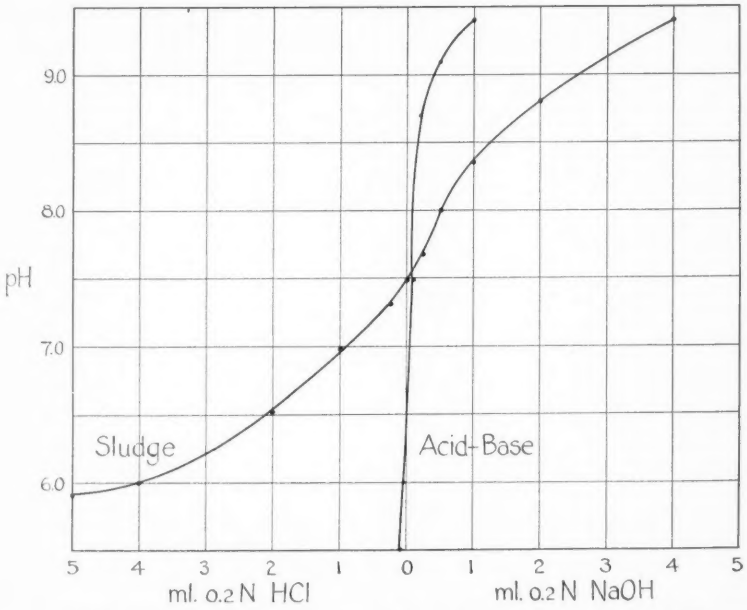

Plate II. Titration Curves for Sludge and Acid-Base

Several samples of sludge were filtered through coarse filter paper which had previously been well washed with distilled water. The filtrate was collected in a 100-cc. graduated cylinder so that delivery was beneath the surface, except, of course, initially. The filtrate changed slowly in pH on standing. In one sample, No. 6, the initial pH was 6.8, in fifteen minutes it was 6.9, in 30 minutes, 7.0, in 60 minutes, 7.1, in 90 minutes, 7.2 and in 120 minutes, 7.3. Of course, a drainable sludge will filter rapidly enough to secure sufficient filtrate for a pH determination in a few minutes. In that case the results will be accurate, providing proper equipment is employed. However, some sludges are gelatinous in nature and filter slowly. The

effect of such filtration is apparent. Filtration under reduced pressure is sometimes employed. This procedure will accelerate evolution of carbon dioxide, and may introduce large errors.

Taken all in all, the special colorimetric method used in this investigation, combined with the dilution procedure, appears to be the most satisfactory method for determining the pH of sewage sludge. The same method can also be applied to many trade wastes and similar materials.

In deciding on the proper dilution for use, it should be kept in mind that the buffer capacity may vary with different sludges, depending on the nature and degree of digestion. Therefore, a safe plan is to dilute no further than is absolutely necessary, in order to make a colorimetric reading. In most cases a dilution of 1 to 9 will prove satisfactory.

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[3] Rettger, Reddish and McAlpine, *Ibid.*, **9,** 327 (1924).
[4] New Jersey Agr. Expt. Sta., *Bull.* **427.**
[5] Fair and Carlson, *J. Boston Soc. Civil Engr.*, **14,** 82 (1927).
[6] Hatfield, *Ind. Eng. Chem.*, **20,** 174 (1928).
[7] Rudolfs, *Public Works,* January, **1927.**
[8] Coburn, *Ind. Eng. Chem.*, **19,** 235 (1927).
[9] Donaldson, *Proc. Thirteenth Annual Meeting N. J. Sewage Works Assn.*, **1928.**
[10] Fischer, *Ibid.*

Compact pH Comparator.—A very compact H-ion comparator is in use in the laboratories of the Sanitary District of Chicago. The outfit was developed by E. Hurwitz, Principal Assistant Chemist. A complete set of indicators and all equipment necessary to determine pH values ranging from 1.8 to 9.2 are contained in a case 9 inches long by 6 inches wide by $8^1/_2$ inches high. Color standards, made with Clark indicators and buffers, are filled into Pyrex tubes holding approximately 1 cc. and mounted on white celluloid cards. The determination is made by drawing the sample into a small pipette from the color reaction plate in which it is prepared and comparing with the standards. The very small quantity of sample required (1 cc.) eliminates to a large extent the effect of turbidity and color and the compactness of the kit lends itself admirably to field work. *Eng. News-Record*, **102,** 704, May 2, 1929.

Effect of Certain Pure Substances on Sludge Digestion[1]

BY H. HEUKELEKIAN[2]

It was pointed out in a previous publication[3] that the carbon–nitrogen ratio in sewage sludge undergoing digestion is important for the metabolism of the microörganisms concerned. Briefly it was mentioned that the microorganisms use various materials for food. The food serves to build up their cells and to furnish energy for their activities. The energy is obtained preferably from carbonaceous materials but in their absence organic substances containing nitrogen can serve as a source of energy. In such cases much more of the nitrogen (in different forms) will be left in the solution as waste product than if carbonaceous materials are utilized as a source of energy. This is due to the fact that microörganisms consume more carbon than nitrogen for energy and store more carbon than nitrogen in their cells. If carbonaceous materials are present these are used up first and the nitrogenous materials are attacked during this period only to the extent to which nitrogen is necessary for the material of the cells of the organisms. After the carbonaceous materials are exhausted the nitrogenous materials may further be broken down, serving as source of carbon and nitrogen.

At the beginning of digestion the ratio is wide and, as a result of decomposition, the ratio narrows until a definite equilibrium is reached. This is accomplished by an elimination of carbon in the form of gases such as methane, CH_4, and carbon dioxide, CO_2, while elimination of nitrogen gas from the decomposing material is proportionately less.

To illustrate the changes in the C/N ratios the following figures are presented:

GRAMS PER CUBIC CENTIMETER

Carbon		Nitrogen		C/N ratio	
Begin	End	Begin	End	Begin	End
1.03	0.72	0.155	0.155	6.6/1	4.6/1

The carbon–nitrogen ratio changed from 6.6/1 in the beginning to 4.6/1 at the end of digestion. The C/N ratio for most vegetable residues is extremely wide; for instance, in straw it is 40/1, whereas in normal soils it has been definitely established at some constant point around 10/1. Sewage solids contain more nitrogen in relation to carbon than vegetable residues or even a normal soil in which decomposition processes are at an equilibrium. It does not seem possible, then, that under normal conditions nitrogen will be a limiting factor in the decomposition of sewage solids.

[1] *Contribution of the Department of Sewage Disposal, Agricultural Experiment Station, New Brunswick, N. J.*

[2] *Research Bacteriologist, Dept. Sewage Disposal.*

[3] *Ind. Eng. Chem.*, **20,** 177 (1928).

After establishing the course of digestion with normal fresh sewage solids of a definite C/N ratio it was thought of interest to modify the C/N ratio artificially by the introduction of some pure substances. From the changes produced by the addition of these substances it should be possible to deduce the changes brought about by the decomposition of similar substances occurring in normal fresh solids. Artificial modifications of the composition of normal fresh solids would be of additional interest in determining the effect of certain wastes received at sewage treatment works on the course of digestion of sludge. Wastes of particular interest include those from paper industries and cotton washings, oils from different sources such as garages and street wash and creamery wastes. In order to study the effect of the most important constituents of these wastes on the digestion of fresh sewage solids, cellulose in the form of filter paper, and oils (a mixture of mineral animal and vegetable oils) were selected to widen the C/N ratio and casein was selected to narrow the C/N ratio.

Methods

Two series of experiments were started. In the first a part of the fresh solids in a mixture of ripe sludge and fresh solids was replaced by pure substances and in the second these substances were added in addition to the proper seeding mixture, according to the scheme below:

Mixture	Ratio*
1—Ripe sludge, fresh solids	1:1.3
2—Ripe sludge, fresh solids, filter paper	1:0.66:1
3—Ripe sludge, fresh solids, casein	1:0.66:1
4—Ripe sludge, fresh solids, oils	1:0.66:1
5—Ripe sludge, fresh solids, filter paper	1:1.3:1
6—Ripe sludge, fresh solids, casein	1:1.3:1
7—Ripe sludge, fresh solids, oils	1:1.3:1

* All ratios given are on the basis of volatile matter.

The filter paper was cut into small pieces but still it was difficult to obtain representative samples at the beginning of the experiment.

The mixture of oils used was made by mixing in equal parts cod-liver oil, olive oil and refined mineral oil (Nujol).

The fresh solids were collected by sinking pails in the flowing-through compartments of Imhoff tanks at Plainfield, New Jersey. The ripe sludge was obtained from the separate sludge digestion tanks at Plainfield. One set of bottles was arranged for gas measurements and another for pH, acidity, alkalinity, solids, ash and biochemical oxygen demand determinations during the course of digestion. The incubator was set at 70° F. but on several occasions the temperature dropped considerably below this point (to 60° F.). This decrease accounts for some of the erratic fluctuations in the rate of gas production. The pH values were determined colorimetri-

cally with a double tube comparator set. Acidity and alkalinity were determined by titration. The B. O. D. determinations were made by diluting portions of the samples with water containing 500 p. p. m. sodium bicarbonate and incubating for 24 hours at 22° C.

The gases were collected and stored in a bottle containing gas-saturated water and the analyses made on the accumulated samples.

Results

The results for pH values, acidity, alkalinity and B. O. D. in the various mixtures for the first 49 days of digestion are presented in Table I. The pH value in the mixture of ripe sludge and fresh solids dropped slightly, but never below 7.0, and within three weeks it reached a value of 7.4. In the mixture in which a part of the fresh solids was substituted by filter paper, the pH value dropped to 6.1 in 15 days, but on longer incubation it reached a value of 7.2 after 36 days and a value of 7.7 after 49 days. The addition of filter paper thus caused a greater depression of the pH value and a greater acidity. In the mixture in which part of the fresh solids was replaced by casein the pH values were approximately the same as in the control, but the titratable acidity was higher than in the mixture to which filter paper had been added. Evidently the alkaline decomposition products of casein maintained the pH at a high value in spite of the higher titratable acidity. The pH value of the mixture to which oils were added dropped to 6.5 within 7 days, but in 20 days it had reached a value of 7.2, and by the 49th day it had reached a value of 7.9. The maximum acidity was higher in this mixture than in the control and was approximately the same as in the mixture to which filter paper had been added.

When these pure substances were added in addition to the regular mixture of ripe sludge and fresh solids the drop in pH values and the increase in acidity was greater than in the experiments in which they replaced a part of the fresh solids. With filter paper a low pH value of 5.8 was reached in 15 days, but after 36 days it had reached a value of 7.4. When casein was added in excess of the normal mixture a low pH value of 6.5 was obtained at the end of 7 days and by the 20th day the pH value had reached 7.2; with the oils a pH value of 6.2 was reached in 7 days and a pH value of 7.2 in 20 days. When these determinations were terminated on the 49th day the pH value of all the mixtures was 7.4 or above. When casein was added to the mixture of ripe sludge and fresh solids the acidity was very high, while the oils did not materially affect the acidity.

The alkalinity of the mixtures, in which cellulose was either substituted for a part of the fresh solids or added in excess, was lower than that of the normal mixture. Casein, on the other hand, produced a very pronounced increase in the alkalinity of the mixture. The increase must have been due to decomposition products of casein such as ammonia, which would tend to

TABLE I

THE EFFECT OF ADDED FILTER PAPER, CASEIN AND OILS ON THE pH VALUE, ACIDITY, ALKALINITY AND B. O. D. OF DIGESTING SEWAGE SOLIDS

	pH Mixture*							Acidity (P. p. m.)							Alkalinity (P. p. m.)							B. O. D. 24-hr. (P. p. m.)						
Days	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	7.3	7.9	7.3	7.6	7.4	7.1	7.3	50	35	140	40	60	185	60	1030	940	1200	910	1030	1200	950	3370	2320	4180	3500	3290	4170	3960
4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3320	2480	6850	3800	3780	7710	4510
7	7.0	6.7	6.9	6.5	6.5	6.5	6.2	80	90	170	100	130	215	150	1140	1080	2940	480	1080	2880	840	3980	2540	7240	2610	4380	6560	4340
12	7.4	6.3	7.0	6.8	6.2	6.8	6.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3550	3190	5980	2930	4380	6950	4240
15	7.0	6.1	7.0	6.8	5.8	6.6	6.3	100	190	230	185	360	370	170	1500	1240	3240	1000	1400	2950	1040	3280	3300	5120	2820	4650	7780	4380
20	7.3	6.7	7.4	7.2	5.9	7.2	7.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3770	3840	6760	3360	4920	8050	3900
22	7.4	6.7	7.4	7.2	5.9	7.2	7.1	90	145	175	90	270	350	20	1630	1280	3290	1190	1250	3380	1300	2590	3950	5270	3250	4700	5290	4450
28	7.6	6.8	7.5	7.2	6.4	7.1	7.3	60	50	110	80	110	340	90	1690	1140	3540	1200	1220	3440	1410	1620	2440	2540	1860	2520	3980	3040
36	7.8	7.2	7.5	7.1	7.4	7.6	7.7	40	60	115	70	35	60	20	1700	1630	3420	1320	....	3430	1620	1300	1690	2740	570	3630	5320	1960
49	8.0	7.7	7.9	7.9	7.8	7.6	7.4	35	35	70	50	60	120	70	1750	1640	3470	1470	1670	3440	1780	650	390	2120	470	2550	4520	650

* See text for composition of mixtures.

TABLE II

COMPOSITION AND YIELD OF GAS

	No. 1—R. S. + F. S.					No. 2—R. S. + F. S. + Filter Paper					No. 3—R. S. + F. S. + Casein					No. 4—R. S. + F. S. + Oils				
Days	Volume Gas* Cc.	% CO_2	Cc. CO_2	% CH_4	Cc. CH_4	Volume Gas Cc.	% CO_2	Cc. CO_2	% CH_4	Cc. CH_4	Volume Gas Cc.	% CO_2	Cc. CO_2	% CH_4	Cc. CH_4	Volume Gas Cc.	% CO_2	Cc. CO_2	% CH_4	Cc. CH_4
1	875	...	...	..	..	590	...	...	...	...	935	...	...	...	...	615	...	...	...	...
4	225	32.4	73	..	..	2730	31.2	850	53.1	1450	1805	30	540	60	1080	750	29.7	220	20.3	152
7	1825	20.0	365	69.9	1272	1705	33.5	570	57.3	975	2440	23.2	565	69.8	1700	1030	19.2	198	63.5	655
12	2185	18.8	410	75.5	1650	2370	29.2	692	64.5	1530	2960	15.6	460	74.3	2200	2740	21.6	590	78.3	2140
15	2510	15.2	379	75.3	1890	2370	24.6	1584	68.8	1610	2180	14.6	318	82.1	1790	2765	16.9	468	74.5	2060
20	2225	12.7	282	71.3	1570	2305	19.8	455	73.5	1690	3055	13.7	418	73.1	2230	2625	14.5	380	76.1	2000
22	2645	14.1	373	73.3	1940	2895	18.1	525	75.2	2180	2575	10.9	280	73.1	1880	2815	14.9	420	82.9	2330
28	2060	14.1	290	73.0	1500	2345	15.0	350	68.0	1600	2975	10.9	325	73.1	2180	3145	15.1	475	81.8	2580
36	2340	12.5	290	73.2	1710	1400	13.6	190	68.0	950	..	..	..	..	..	3005	13.6	408	66.8	2000
49	335	14.6	52	80.3	285	..	..	..	..	..	..	..	..	..	..	4425	13.6	600	66.8	2950

* Accumulated between readings.

maintain the pH value at a higher level in spite of the greater accumulation of acids. When oils were added to the ripe sludge either in excess or as a partial replacement of fresh solids, the alkalinity was not effected materially. It is possible that if these determinations were continued over a longer period a marked difference might have been noticed. This seems the more probable since the oils decomposed slowly.

When filter paper was added to the digesting mixture to replace part of the fresh solids, the effect on the biochemical oxygen demand was not so pronounced as when it was added in excess of the normal mixture. With the addition of casein to the mixtures the B. O. D. was very markedly increased in the both cases. The action of oils was intermediate to that of cellulose and casein.

These results indicated that alteration of the composition of fresh solids by the substitution of definite known substances brought about very marked changes in the course of digestion. When these substances were added in addition to the normal quota of fresh solids, even more striking differences were noticed. The pH value was invariably lowered, to the maximum degree by filter paper and the least by casein. Surprisingly, casein gave rise to a higher acidity than filter paper and this in spite of higher alkalinity.

Rate of Gas Production

The rates of gas production in the various mixtures are shown in Figures 1 and 2. The mixture of ripe sludge and fresh solids reached the peak of gas production in about 21 days; after 35 days the maximum rate of gas production was over and after 45 days the minimum rate was reached.

When filter paper was substituted for a part of the fresh solids there was an initial peak of gas production followed by a secondary peak. The secondary peak occurred ten days later than the peak of the control mixture. The initial peak is not due to the decomposition of filter paper, since it was shown in a previous paper[1] that the decomposition of filter paper started after a lag period extending from 5 to 7 days. But when the proportion of fresh solids to ripe sludge was reduced in order to replace some of the fresh solids by filter paper, with a seeding ratio of 1/0.66 between ripe sludge and fresh solids, the decomposition of the latter proceded at a faster rate than where the seeding ratio was 1/1.3.

While the partial replacement of fresh solids by filter paper caused a 20 per cent increase in the time of digestion, the addition of an excess of filter paper to the normal mixture caused a 100 per cent increase. In the latter case there was a prolonged period of low rate of activity and the peak of gas production did not occur until the 70th day; the magnitude of the gas peak even then was less than half as high as in the mixture in which filter

[1] *N. J. Agr. Expt. Sta., Sixth Annual Rept.*, 272–284 (1927).

paper was added to replace part of the fresh solids. It should be borne in mind that the weight of filter paper added was the same in both cases, the only difference being in the quantity of fresh solids added. The seeding ratios in the first and second filter paper mixtures were 1/1.66 and 1/2.3, respectively. It has been established that the digestion is completed in 35 days at 70° F. with a seeding ratio of 1/2 (on the basis of volatile matter). Obviously this generalization applies only to domestic sewage and if wastes high in cellulose are to be digested, sufficient allowance must be made in calculating the capacity of the tanks both for the additional load and the retardation of digestion.

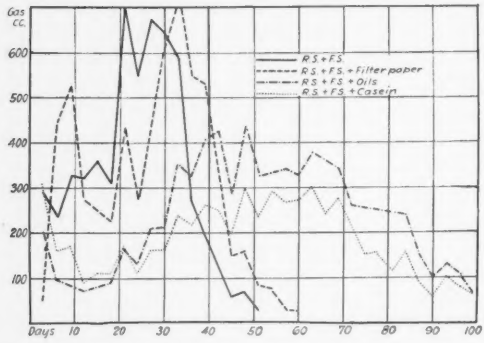

FIG. 1.—Gas Production from Mixtures of Ripe Sludge and Fresh Solids in Which Part of the Fresh Solids Was Replaced by Pure Substances (3-Day Averages).

Gas measurements in the mixture containing an excess of filter paper were discontinued after 110 days. It is probable that if measurements had been continued for a longer period a secondary peak of gas production might have been obtained, as in the other mixtures of the same series. This view is substantiated by the low gas yield, as will be pointed out later.

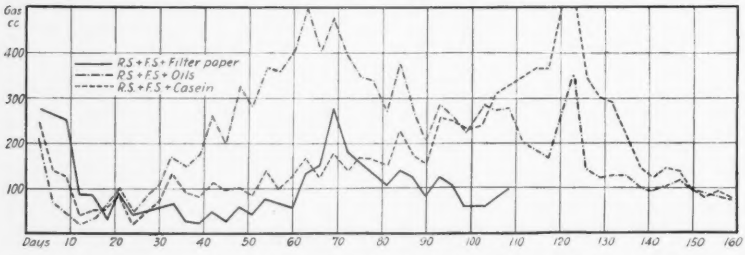

FIG. 2.—Gas Production from Mixtures of Ripe Sludge and Fresh Solids to Which the Pure Substances Were Added as an Overload (3-Day Averages).

There is no correlation between pH values, or acidity and the rate of gas production. The pH value on the 36th day had reached 7.4 without a corresponding increase in gasification. The increase in gas production took place only after 60 days. Although the pH determinations were made on samples from bottles which were being opened occasionally for analysis

and the bottles for gas measurements were not opened at all, the discrepancy in gas production can hardly be explained by these differences. It seems more probable that with sewages containing wastes of various kinds the pH is not an index of gasification.

When casein or oils constituted a part of the raw material added there was a decided retardation in the rate of gas production. The retardation was greater when these substances were added in excess of the 1/1.3 ratio of ripe sludge to fresh solids. When these substances were added in excess it required approximately 90 days before the minimum rate of gas evolution was reached, as compared with 45 days for the control. The rate of gas production with casein was lower than that with oils. When casein was added in excess of the 1/1.3 ratio of ripe sludge to fresh solids, the rate of gas evolution was low and increased only very gradually, so that the peak was not attained until the 120th day of incubation. When oils were added to mixtures of the same composition the peak of gasification came after the 60th day, with a secondary peak of minor magnitude on the 125th day.

The yield of gas per gram of raw volatile matter added was greatest with the mixtures to which oils were added and lowest with cellulose (Table III). Casein occupied an intermediate position. A yield of 272 cc. of gas per gram of raw volatile matter added in the 1/1.3 mixture of ripe sludge and fresh solids which had received cellulose is obviously very low in comparison with the gas yield of 735 cc. from the control mixture. As previously mentioned gas measurements for this mixture were discontinued after 110 days and it is possible that had they been continued for a longer period a second peak in gas production might have been obtained. This is substantiated by the comparatively low reduction of volatile matter in this mixture as compared with the mixture in which filter paper was substituted for some of the fresh solids.

If we assume that the fresh solids were decomposed to the same extent and produced the same amount of gas whether digested alone or in combination with the pure substances employed, we can deduct from the total gas yield that volume due to the fresh solids and the remainder would be due to the substances added. The results calculated on this basis show that the oils were richer sources of gas than the fresh solids, cellulose or casein.

Composition of the Gas

The percentage and the amounts of carbon dioxide and methane in the accumulated gases from the first four mixtures are given in Table II. The amounts of total gas, methane and carbon dioxide per gram of raw volatile matter are given in Table III. The addition of cellulose increased the amount and the average percentage of carbon dioxide and decreased the yield of methane. No appreciable difference from the control was noted

in the composition and yield of these gases when casein was added. With the oils the yield of carbon dioxide and methane per gram of volatile matter added increased, although the average percentage of carbon dioxide was nearly the same as from the control and that of methane somewhat reduced.

TABLE III

TOTAL YIELD AND AVERAGE COMPOSITION OF THE GAS AND THE REDUCTION OF VOLATILE MATTER IN THE MIXTURES TO WHICH FILTER PAPER, CASEIN AND OILS WERE ADDED

	I	II	III	IV	V	VI	VII
	R. S. + F. S.	R. S. + F. S. + Filter Paper	R. S. + F. S. + Casein	R. S. + F. S. + Oils	R. S. + F. S. + Filter Paper	R. S. + F. S. + Casein	R. S. + F. S. + Oils
Amounts of raw material added, gms.	F. S. = 23.5	F. S. = 11.7 Filter paper = 17.7	F. S. = 11.7 Casein = 17.7	F. S. = 11.7 Oils = 17.7	F. S. = 23.5 Filter paper = 17.7	F. S. = 23.5 Casein = 17.7	F. S. = 23.5 Oils = 17.7
Volume gas produced, cc.	17,225	18,710	18,925	23,195	11,240	28,100	33,050
Cc. gas per gram of raw volatile matter added	735	637	643	796	272	680	800
Cc. gas per gram of pure substance added	...	572	584	835	...	610	890
Cc. CO_2 per gram of raw volatile matter added	106	143	99	128	...	...	...
Cc. CH_4 per gram of raw volatile matter added	505	406	445	575	...	...	...
Average per cent CO_2	17.1	25.6	14.1	17.7			
Average per cent CH_4	74.0	66.0	72.2	68.0			
Per cent reduction of volatile matter in 20 days	20.8	..	34.0	9.1	..	31.4	11.0
Per cent reduction of volatile matter, total	36.5	53.1	54.8	48.1	36.0	51.6	48.2
Time for completion of digestion, days	45	55	90	100	100	160	160

Volatile Matter Reduction

The reduction of volatile matter within 20 days and at the termination of digestion for each mixture are given in Table III.

The reduction of volatile matter in the filter paper mixtures after 20 days was not calculated since no representative sample could be obtained. The casein mixtures indicated a reduction of 34 per cent, a value greater than that in the control. The oil mixtures gave reduction of volatile matter less than the control. As a rule the reduction of volatile matter at the end of digestion was greater in the mixtures to which the various substances

were added than in the control mixture, but the greater reduction of volatile matter was not necessarily accompanied by a greater gas yield. Mixtures with low gas production per gram of added raw volatile matter indicated equal or greater reduction of volatile matter than those with high gas yields. An actual loss of volatile matter due to liquification is not conceivable since all the liquid remained in the bottles. It has been shown[1] that the loss is merely apparent and is caused by the volatilization of liquefied substances when the sample is dried in an oven for solids determinations.

Summary and Conclusions

Two sets of digestion experiments were made—one, in which the amount of fresh solids in the original mixture was reduced and supplemented by the addition of definite amounts of filter paper, casein and oils; and two, in which the control ratio of ripe sludge to fresh solids was maintained and the known substances were introduced in addition. The results show that:

1. The addition of these substances lowered the pH value and increased the acidity, the extent depending on the mixture and the substance added. Filter paper produced the maximum lowering of the pH value, but the greatest acidity was obtained with casein, coincident with a comparatively high pH value. The addition of oils resulted in a lowering of the pH value intermediate between that of casein and filter paper. The changes were more pronounced when larger proportionate amounts of these substances were added.

2. The alkalinity was lower in the mixtures with filter paper and oils than in the control, and was highest in the mixtures with casein.

3. The B. O. D. increased with the addition of all substances; the increase was greatest with casein and lowest with oils. Again the mixtures receiving the greater proportion of fresh solids indicated more pronounced effects.

4. The completion of digestion as indicated by gas production was retarded approximately 10 days by the substitution of filter paper for fresh solids. Where casein and oils were substituted for fresh solids, the digestion time was nearly doubled. The addition of all these substances as an overload increased the time of digestion to even a greater extent than when they were used as substitutes for a part of the fresh solids.

5. The yield of gas per gram of added raw volatile matter was greatest when oils were added. Filter paper and casein gave yield lower than the control.

6. The addition of filter paper to the digesting mixture increased the average percentage as well as the total yield of carbon dioxide and caused a decrease in the content of methane. Addition of casein did not change

[1] *Ind. Eng. Chem.*, **21**, 324 (1929).

materially the yield of methane and carbon dioxide or the average percentage of these gases. Presence of oils increased the yield of carbon dioxide and methane without a corresponding increase in the average percentage of these gases. The increase was due mainly to the greater yield of gas per gram of volatile matter.

7. There was a greater apparent reduction of volatile matter in the mixtures to which the various substances were added than in the control mixture. Such increases in the reduction of volatile matter were not accompanied by increase in gas yield.

Gas from Corn-stalks by Biological Digestion.—At the most recent meeting of the American Chemical Society at Minneapolis, September 9–13, 1929, Dr. A. M. Buswell reported the results of his preliminary experiments at Urbana, Illinois, on the use of corn-stalks for production of an inflammable gas for use on the farm.

The results of this work are an outgrowth of Dr. Buswell's work on cellulose digestion. Various types of cellulosic materials such as paper pulp, wood pulp, filter paper and shredded corn-stalks were digested with sewage under controlled conditions and the rate of gas production was observed.

The experiments were carried on for the purpose of determining what types of materials digested most readily, the conditions necessary for good digestion and the amount and composition of the gas evolved.

A satisfactory yield of gas having a high fuel value was obtained. Experiments were then started to study the conditions under which the maximum amount of gas could be produced.

Corn-stalks produced gas yielding 35–50 per cent of the weight of raw material.

Results of Operation of Experimental Contact Filter with Partially Submerged Rotating Plates

BY J. DOMAN[1]

Sand filters, sprinkling filters, contact beds and the activated-sludge process have been developed as methods of treating sewage by providing contact between the sewage and what might be termed "active aerobic material." Some years ago the thought occurred to the writer that sewage may be treated aerobically by a somewhat different method than those already developed. The main thought was to provide a non-reacting substance upon which a thin film of sewage material would collect and by alternately submerging this substance with the adhering film into the sewage and then exposing it to the atmosphere, a coating similar to that on sprinkling filters would be developed and provide aerobic treatment when brought in contact with the sewage.

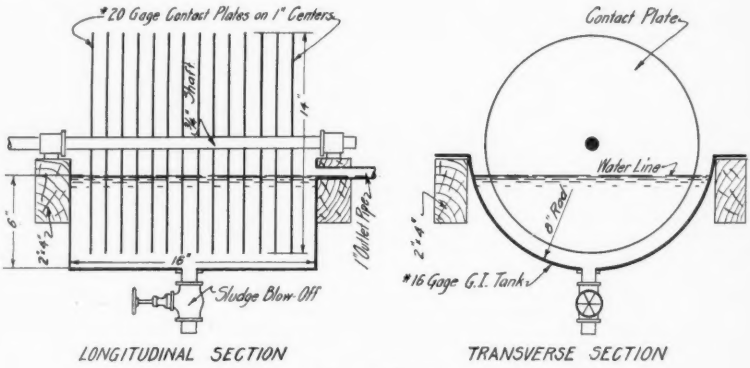

FIG. 1.—Experimental Plant, Constructed March, 1925.

Several forms of apparatus suggested themselves for carrying this idea into effect, the simplest being of a partially submerged rotating type. In the early part of 1925 such a filter, as shown in Figures 1, 2 and 3, was designed and constructed by the writer and operated in two periods totaling in all approximately twenty weeks. Some interesting observations were made during operation of the plant.

Description of Plant.—Sewage taken directly from a 300-gallon septic tank was used as the influent to the experimental plant. This septic tank received the wastes from two toilets and two lavatories used by eight employees of a small factory. From the septic tank, the sewage was pumped by a hand pump into a 50-gallon barrel. A continuously operated bucket

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elevator removed the sewage from the barrel, discharging it into a launder leading to the contact tank. This tank was 16 in. long, semi-circular on an 8-in. radius. The volume below the flow line was 4.75 gallons. In the tank was placed a series of circular plates of 20-gage galvanized iron fastened to a central horizontal shaft. There were 14 plates, each 14 in. in diameter and spaced on 1-in. centers. A $^1/_2$-H. P. motor was provided for continuously revolving the plates and operating the bucket elevator. From the contact tank, the sewage flowed into a small settling tank of the Imhoff type, the flow chamber volume being 7.5 gallons. The entire apparatus was placed outdoors. A removable metal cover was provided over the contact tank as protection against the weather.

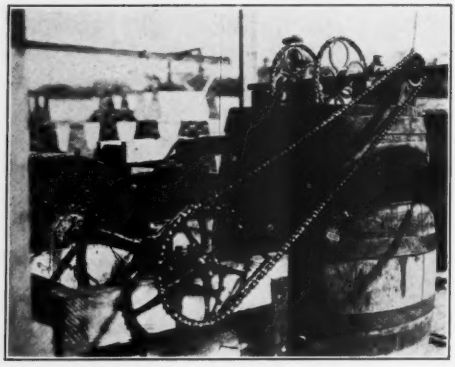

FIG. 2.—Mechanism for Operating Plates and Bucket Elevator.

Two major runs were made, the first from March 21 to June 10 and the second from Sept. 7 to Oct. 29, 1925. Operation was continuous throughout the 24-hour day for both runs. From the mechanical standpoint, operation was very satisfactory, as there was only one shut-down of a few hours during the second run.

First Run.—Operation was started with an average sewage flow of 2.8 gallons per hour, this providing a retention period of 1.7 hours in the contact tank. The plates were rotated at 1 r. p. m. A coating began to develop on the plates within three days after starting operation and at the end of two weeks this had grown to a thickness of about $^1/_{16}$ in. on each side of the plates. The coating was gray in color and had a somewhat curdled gelatinous appearance. At the end of two weeks' operation, the removal of turbidity from the sewage was about 35 per cent. A month after starting operation the coating grew to a thickness of about $^1/_8$ in. on each side of the plates and became heavy enough to start sloughing off. The effluent was still very turbid; tests indicated that only about one-third of the turbidity was removed by the process.

After the first month of operation it was quite apparent that results were not comparable with other forms of aerobic treatment. Improvement was attempted by decreasing the rate of rotation of the plates from 1 r. p. m. to $^1/_2$ r. p. m. and increasing the retention period in

the contact tank from 1.7 hours to approximately 6 hours. These rates were continued for about six weeks but there was no improvement in results. Material on the plates continued to peel off when sufficiently thick and heavy. This material was black and septic for about half its thickness next to the plates, and had a distinct odor of hydrogen sulphide.

Throughout this run the sewage from the septic tank was very odorous and apparently in such condition as to prevent the development of aerobic growths on the plates, in spite of the aeration received when the growths were exposed to the atmosphere. Apparently the growths acted as colloiders to some extent but were not able to effect aerobic purification. Analysis of samples taken during this run are shown in Table I.

TABLE I

ANALYTICAL DATA

Results in Parts per Million

Determination	Run 1 Sample of Apr. 30, 1925 Influent	Effluent	Per Cent Removal	Run 2 Sample of Oct. 11, 1925 Influent	Effluent	Per Cent Removal
Nitrogen as org. N	..	..	..	18.4	7.2	61
Alb. Amm.	6.0	3.5	42	..	..	..
Free Amm.	39.0	45.0	−15	20.0	18.0	10
Nitrites	0.0	0.0	..	0.0	0.0	.
Nitrates	0.0	0.0	..	0.0	4.0	..
Ox. Cons.	96	71	26	62	45	27
Susp. Sol.						
Tot.	..	..	..	38	7.5	80
Volatile	..	..	..	35	7.0	80
Turbidity	290	150	48	..	..	..
Chlorides	54	54	..	28	29	..
Alkalinity	314	..	..	198	157	21

Analyses for Run 1 by Connecticut State Health Department.

Analyses for Run 2 by Richard C. Smith, Chief Chemist and Bacteriologist, Passaic Valley Sewerage Commission.

Second Run.—It was felt that the poor results from the first run were due largely to the hydrogen sulphide in the septic sewage and that reduction of this constituent and the addition of some dissolved oxygen to the sewage would condition it so that it would support an aerobic growth on the plates. Three wooden trays were therefore made so that prior to entering the contact tank, the sewage could flow over them in thin layers, thus allowing the escape of some hydrogen sulphide and absorption of oxygen by the sewage. These trays are shown in Figure 3.

The second run was started Sept. 7 and ended Oct. 29, 1925, a period of seven weeks. During this period the sewage flow was 2 gallons per hour, giving a retention period of 2.4 hours in the contact tank. The plates were cleaned prior to starting the run and during the run were rotated at a rate of $\frac{1}{2}$ r. p. m.

A very thin coating was obtained on the plates, the thickness at the end of six weeks' operation not exceeding $^1/_{32}$ inch. The coating was brown in color and the particles knitted together to form a homogeneous thin skin. During this period the coating never peeled from the plates. In several places it was purposely torn off to see if it had turned septic where attached to the plates. This, however, was not the case, the inner surface having the same appearance as the outer. The film had only a slightly stagnant odor.

FIG. 3.—Contact Plates and Wooden Tray Aerator.

The removal of turbidity on the fourth day of operation during this run was about 35 per cent and at the end of the first week well over 50 per cent. At the end of the second week the removal of turbidity ranged consistently from 75 to 90 per cent. The effluent from the process was practically odorless. Analyses of samples collected Oct. 11, 1925, about five weeks after starting operation, are shown in Table I.

Discussion of Analyses.—The results from the first run show poor clarification and no oxidation of organic matter. The increase in the free ammonia content of the effluent is attributed to septic action taking place in the coating. It was very evident from observation that aerobic purification was not obtained during this run and the analyses and percentage removals corroborate this conclusion.

Results and percentage removals for the second run, however, are characteristic of aerobic processes. Very good clarification is indicated by the removal of suspended solids. Reduction of organic nitrogen is quite satisfactory. Oxidation of organic matter is shown by the decrease of free ammonia accompanied by the production of nitrates. There is also the characteristic lowering of alkalinity which accompanies the reduction in free ammonia and increase in nitrates. It seems conclusive that aerobic purification was being obtained during this run.

Mention might be made of one peculiarity of the results, namely, the small percentage removal shown by the oxygen consumed tests. This may be due to the presence of an abnormal amount of soapy water in the wastes entering the factory septic tank.

Conclusions.—The following conclusions are drawn from these experiments.

(1) For successful operation the sewage must be in such condition that it will induce an aerobic growth on the rotating plates similar to the growth on the stones of sprinkling filters.

(2) If the growth is anaerobic the main action taking place will be that of clarification, the growth serving as a colloider and apparently being able to coagulate about 50 per cent of residual colloids. Even prolonged contact (6 hours) with this growth did not improve clarification beyond this degree and did not induce aerobic purification.

(3) When the growth is anaerobic in character it will eventually become septic.

(4) With an aerobic growth on the plates and a proper retention period in the contact tank the effluent obtained will be similar to the clear, stable effluent produced by other aerobic processes.

(5) No septic action was observed in the aerobic growth during the seven week period (Run 2) of successful operation. Further tests are required to determine the behavior of this growth. It is expected, however, that it will unload at times. Provision should therefore be made to remove this material prior to final discharge of the effluent.

(6) As the aerobic growth was obtained on perfectly smooth galvanized-iron plates as well as on plates that had been mortar-coated, it seems safe to assert that the growth can be obtained on any non-reacting material without danger of washing away. The character of the growth will depend to a very considerable extent upon the condition of the sewage entering the plant.

(7) The vertical-plate filter used in the experiments was not a very efficient arrangement. Although the coating formed and clung to the plates, particles of suspended matter in the sewage could be observed attaching themselves to the plates as they emerged from the liquid, but upon next entering the liquid, these suspended particles would wash off the plates. A more efficient arrangement would provide a sort of "blanket" effect by using either thin expanded metal wound in circular layers or plasterers' lath laid in circular layers. The expanded metal would be suitable only for experimental purposes since it would eventually rust out.

(8) Only one filtration compartment was used in the experimental plant. A better arrangement would be to provide several filtration compartments in series, designed for continuous flow.

(9) There was considerable sedimentation in the filtration compartment and apparently very little in the settling compartment. By removing the solids from the filtration compartment continuously, either mechanically or by using the Imhoff tank design, it is concluded that only a small retention period need be provided in the settling compartment.

(10) Characteristic aerobic purification was obtained in the second run with a retention period of 2.4 hours in the filtration compartment. No

attempt was made to determine the minimum retention required for satisfactory results.

(11) Further experimental work is required to determine critical operating rates including retention periods in filtration and secondary settling compartments, speed of rotation of the apparatus, required amount of surface exposed by the filter and also temperature effects, particularly during the winter months. The writer has designed an improved apparatus for experimental work on a larger scale, but opportunity has not been presented to construct and test it out.

The Biologic Wheel.—An experimental rotating contact wheel has been operated for several months in 1929 at Hammond, Indiana. The wheel was developed by the Paige and Jones Chemical Company under patents held by A. T. Maltby. The apparatus consists of a series of paddle wheels with twelve or more blades, supported over a channel, with small clearance at the sides and bottom. The flow of sewage rotates the wheels, alternately submerging and exposing the blades. These blades accumulate biologic growths which absorb oxygen while exposed to the air.

A small experimental plant has been operated at Hammond with recirculation of sewage by pumping. With an estimated detention period of four hours, and twelve blades on the paddle wheels, approximately fifty per cent reduction in B. O. D. was obtained. When the contact period was increased to six hours, and the number of blades to thirty-six, B. O. D. results indicated a purification of from sixty to eighty per cent. Analyses were made under the direction of Dr. A. M. Buswell, who has rendered a report to the Paige and Jones Company. Dr. Buswell claims the following advantages:

1. The area required is about 1/10 that for trickling filters.
2. The power cost is low as compared with the activated sludge process.
3. Nitrification is accomplished. This has not yet been effected with the modified colloiders of Imhoff and Buswell.

The report deals only with the results obtained, and does not include an analysis of cost data, although Dr. Buswell states that "the low operating cost should be very attractive to cities requiring large installations." *Sewage Disposal Bulletin, City of New York,* Kenneth Allen, p. 14, July, 1929.

Effect of Aeration and Protozoa on *B. coli* in Sewage*

BY H. HEUKELEKIAN** AND WILLEM RUDOLFS†

The viability of *B. coli* in polluted water and sewage has attracted the attention of a number of investigators. Various factors such as temperature, storage, activity of other organisms, food supply, sedimentation, products of decomposition, sunlight and bacteriophage have been considered to play some part in the reduction of the numbers of *B. coli*. The influence of air has not been fully studied. Whipple and Mayer[9] have found that typhoid and colon bacilli survive longer in water under an atmosphere of air than under an atmosphere of hydrogen. Hinds,[3] using a somewhat different technique, reported directly opposite results. It was, therefore, thought of interest to evaluate more definitely the influence of air on the viability of *B. coli*. The direct and indirect action of air may be a factor in the reduction of *B. coli* in the self-purification of streams. The part played by air in the reduction of *B. coli* in the activated sludge process and in sewage sprinkling filters may also be important.

Method

Sewage from different units of a disposal plant was aerated for different periods. *B. coli* determinations were made by introducing dilutions into standard lactose broth tubes. Confirmations were made on eosin methylene blue agar but the results are not expressed on the basis of confirmation because it was found during the experiment that only a low percentage of the positive lactose tubes showed any growth on the agar. Contact with high acidity, produced in 48 hours in lactose tubes had reduced the numbers of *B. coli* to such an extent that subsequent confirmation was erratic and unreliable. It is, therefore, now a practice in our laboratory to make the confirmation at the end of 24 hours and to incubate the tubes which do not show any gas formation for an additional 24 hours.

Results

The results of three hours of continuous aeration of screened sewage, settling tank effluent and sprinkling filter effluent are given in Table I together with pH values, CO_2 acidity, dissolved oxygen and *B. coli*. The *B. coli* counts were erratic but no reduction in their numbers took place during the 3-hour aeration period. In the screened sewage *B. coli* showed a tendency to increase. The pH value and the dissolved oxygen increased while the dissolved CO_2 decreased during aeration.

* *Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Sewage Disposal.*

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TABLE I

Time, Min.	Screened Sewage				Settling Tank Effluent				Sprinkling Filter Bed Effluent			
	B. coli per Cc.	pH	CO_2, P. p. m.	Dis. O_2, P. p. m.	*B. coli* per Cc.	pH	CO_2, P. p. m.	Dis. O_2, P. p. m.	*B. coli* per Cc.	pH	CO_2, P. p. m.	Dis. O_2, P. p. m.
0	10,000	7.3	6.6	0	100,000	7.1	6.6	0	10,000	6.9	6.6	2.5
5	1,000,000	7.4	4.4	2.4	100,000	7.4	4.4	1.8	1,000	7.2	4.4	5.0
15	100,000	7.7	2.2	4.5	10,000	7.7	2.2	3.6	10,000	7.7	2.2	5.8
30	10,000	7.9	2.2	4.8	100,000	8.1	2.2	4.5	10,000	7.9	2.2	6.4
60	100,000	8.4	2.2	5.5	100,000	8.6	2.2	6.2	10,000	8.5	2.2	6.4
120	100,000	8.6	2.2	6.4	100,000	8.6	2.2	6.5	100,000	8.6	2.2	7.3
180	1,000,000	8.6	2.2	7.0	100,000	8.7	2.2	8.0	10,000	8.7	2.2	7.6

Pump delivered 5.6 gal. of air per minute into 5 gallons of liquid.

It was thought that the coarse particles in the screened sewage might have caused the fluctuation in the *B. coli* determination; hence for the second series a sample of settling tank effluent was used after being strained through cotton. The effluent was aerated continuously for 72 hours.

The results of the previous series were checked in so far as no *B. coli* reduction was shown by aeration for 24 hours or even for as long a period as 72 hours (Table II). Fluctuations were not eliminated by the precaution of straining.

TABLE II

Hours	*B. coli* per Cc.
0	45,000
2	140,000
4	1,100,000
6	110,000
8	200,000
10	250,000
12	1,400,000
	Over
24	140,000
	Over
31	140,000
	Over
48	140,000
56	45,000
72	140,000

Further studies were conducted on the effect of intermittent aeration over a prolonged period on the reduction of *B. coli*. Quantities of tank effluent were strained through cotton and divided into equal portions. One portion was left untreated and the other was aerated for 15 minutes every day by means of an electric pump. A condensed summary of the results of lactose fermentation tests are given in Table III. A 94 per cent reduction in the number of organisms occurred in 7 days in the unaerated sewage. In the aerated sewage there was no reduction in 7 days, but 80 per cent reduction in 12 days. Since there was no reduction by continuous aeration for 3 days it is possible that the reduction took place between the 3rd and the 12th

days. This is, however, not certain since the action of intermittent aeration may be different from that of continuous aeration. The tendency for intermittent aeration to postpone the reduction in the bacterial number is, however, clearly brought out.

TABLE III

Days	Unaerated		Aerated	
	B. coli per Cc.	Per Cent Reduction	*B. coli* per Cc.	Per Cent Reduction
0	45,000	..	110,000	..
7	2,500	94.0	110,000	0
12	950	98.0	20,000	82
16	Less than 40	99.9	1,500	99

Discussion

What is the explanation for the effect of air in initially increasing and postponing the final reduction of *B. coli?* The aeration drives off the CO_2 faster than it is produced and increases the pH value of the sewage from 7.3 to 8.3 (Figure 1). Although it is conceivable that this might create a more favorable environment for the *B. coli*, it is probably not the cause of the increase because the pH of the unaerated sewage does not go much below 7.0. The minimum pH that *B. coli* can tolerate is lower than this value. Aside from lowering the pH value the CO_2 itself would have no detrimental effect on bacteria, as has been shown by Valley and Rettger.[7] Organic acids produced during aeration would be lower than under complete anaerobic conditions. It is possible that *B. coli* might thrive better in the presence of some dissolved oxygen than under complete anaerobic conditions. Although *B. coli* does not actually require atmospheric oxygen for its growth, the presence of dissolved oxygen may bring about some indirect influences favorable for its existence. Of these, mention might be made of the differences in the products of decomposition under aerobic and anaerobic conditions. The influence of higher organisms such as protozoa may be more favorable to *B. coli* under aerobic than under anaerobic conditions. But such does not seem to be the case from the results of studies reported by Schut[6] and Van Loghem and Ruys.[8] They found that when the content of dissolved oxygen (as measured by stability tests) of a septic tank effluent decreased, the protozoa capable of clearing

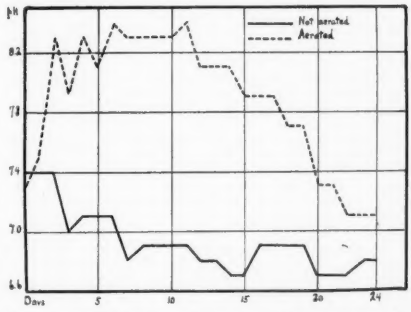

FIG. 1.—pH Values of Aerated (Intermittent) and Unaerated Imhoff Tank Effluent.

up a suspension of typhoid and dysentery bacilli and cholera vibrio disappeared. As soon as the septic tank was rested and the dissolved oxygen content increased, protozoa which were able to kill the bacteria (ciliates) reappeared.

The factor which undoubtedly plays an important rôle in causing the initial increase in numbers of *B. coli* is the breaking up of the colloidal aggregates of organic matter and clumps of bacteria during aeration. The fact that aeration of screened sewage caused a greater rise of *B. coli* than the aeration of trickling filter effluent might be explained on this basis.

It should further be stated that in the last series the unaerated sewage was sampled without shaking. It occurred to us that sedimentation might have played a part in the reduction of *B. coli*. Therefore, when the experiment was terminated after 16 days the sewage was aerated for 15 and 45 minutes. The *B. coli* numbers increased from less than 40 per cc. to 200 and 2500 at the end of 15 and 45 minutes of aeration, respectively. This would indicate that the more rapid reduction of *B. coli* in unaerated sewage was due to settling of *B. coli* in conjunction with the suspended particles, while the apparent extension of the longevity of *B. coli* might be merely a question of increased counts caused by breaking up of the aggregates during aeration.

Our experiments would seem to support the view of Whipple and Mayor that *B. coli* survive better in the presence of air than in the absence of air. The conditions under which the experiments were conducted were different. They stored the water in the presence of air while in our experiments air was passed through sewage in a vigorous stream which might have broken up the particles.

Our experiments show further that a substantial reduction of *B. coli* in stored sewage does not take place in less than 7 days. Similar results were obtained by Winslow and Cohen[10] with stored water.

One of the most important features of aerating processes of sewage treatment is the high bacterial purification. Properly functioning sprinkling filters will accomplish 80 to 85 per cent reduction of bacteria, while with the activated sludge process 90 to 95 per cent reduction may be obtained. It appears that the reduction of the intestinal forms of bacteria in the sewage by aerating processes is due, first, to a straining or adsorbing action of the active surfaces and second, after the bacteria are separated from the sewage into the film of a filter or the flocs of activated sludge the activity of other organisms, along with other unfavorable conditions, will reduce their numbers. Russell and Bartow[5] ascribe the large reduction to settling and the activity of higher organisms.

The following figures were obtained from a 36-hour study of the activated sludge plant at Tenafly, N. J., and are presented here to throw some further light on this question.

	Screened Sewage	Aeration Tank	Clarifier Effluent
B. coli per cc.*	31,470	28,500	4,460
Total solids, p. p. m.*	450	4,500	328
B. coli per total solids	70	6	13
Suspended solids, p. p. m.*	77	4,200	20
B. coli per suspended solids*	410	7	223

* Average of samples taken $1^1/_2$ hours apart during the day.

The relation between *B. coli* and solids in the effluent, aeration tank and clarifier effluent are of interest. Although the units of expression for *B. coli* and solids are different, for the purpose of comparison it is immaterial, since the relationship would not be changed if solids were expressed in grams per cubic centimeter. It will readily be seen from these figures that the sum of *B. coli* in the aeration tank and the clarifier effluent is nearly equal to the count in the influent, but if the results are expressed on the basis of total solids, the sum of *B. coli* in the aeration tank and clarifier effluent is about one-third of the number present in the influent. On the basis of suspended solids a similar relationship may be noted. There is, therefore, a reduction of *B. coli* even when the factor of settling and differences in the suspended solids in the different units is eliminated, so that not all the reduction of *B. coli* can be explained on the basis of settling. At Tenafly the returned sludge is not re-aerated, therefore, the reduction of *B. coli* must take place in the aeration tank. Thus flocculation of suspended solids and of *B. coli* as well as reduction of *B. coli* take place simultaneously in the aeration tank. The aeration period at Tenafly was 6 hours. Since the studies reported above showed that air *per se* does not have a deleterious effect on *B. coli*, it would seem that the reduction in the aeration tanks is due to some other factor, possibly the influence of higher organisms.

Results obtained from a 36-hour study at the activated-sludge plant at Mamaroneck, N. Y., are similar to those obtained at Tenafly, but the numbers of protozoa (grouped together as ciliates and flagellates) are also available:

	Screened Sewage	Aeration Tank	Clarifier Effluent
B. coli per cc.	34,500	..	20,300
Total solids p. p. m.	1,322	..	1,247
B. coli per total solids	26	..	16
Protozoa per cc.	902	37,000	2,570
Ciliates	830	2,900	55
Flagellates	72	34,100	2,020

These results were obtained on July 14 and 15, 1926, two weeks after the plant was put in operation. The reduction of *B. coli* was only 41.3 per cent, with an actual increase of the numbers of protozoa in the effluent. Most of the protozoa in the activated sludge were small flagellates, which

are characteristic of a poorly-operating aeration tank. *B. coli* counts were not determined in the activated sludge but since their numbers, on the basis of solids in the aeration tank, are very small, it is probable that these organisms will not appreciably affect the results. On the basis of solids, the reduction of *B. coli* from influent to effluent is less than was obtained at Tenafly.

In contrast with these results a study made on September 28 to 29, 1926, at Mamaroneck is interesting:

		Screened Sewage	Aeration Tank	Clarifier Effluent
B. coli per cc.		23,100	..	255
Total solids		1,470	..	1,090
B. coli per total solids		15	..	0.2
Protozoa per cc.	ciliates	995	4,200	516
	flagellates	355	460	110

At this time the reduction of *B. coli* from the influent to the effluent was 98.9 per cent. In relation to the solids *B. coli* decreased to a greater extent than in the previous run. Protozoa decreased in the effluent. The total numbers of protozoa were smaller in the aeration tank, but they were mainly ciliates, in contrast with the large percentage of flagellates in the previous run. Actually the numbers of ciliates per cc. were greater. It has been pointed out in a previous paper[4] that in an efficiently working aeration tank a preponderance of ciliates is present over flagellates. It is evident also that an efficient working tank produces a greater reduction of *B. coli* per unit of solids treated. It should be kept in mind that in both instances the amounts of air per given quantity of sewage was practically alike, but in the first instance the sludge had become septic.

In an efficient sprinkling filter the numbers of ciliates are constantly greater than the numbers of flagellates. Also the individual size of the ciliates (*Opercularia* is the predominant form) is far greater than the individual size of the flagellates (1), and the numbers of *B. coli* are greatly reduced (2). Air maintains a predominant aerobic flora and fauna in the film which causes the reduction of *B. coli* adsorbed from the flowing sewage. Although the direct effect of air on *B. coli* is probably insignificant, the indirect result is very important.

Summary

It has been shown that aeration does not cause a decrease in the numbers of *B. coli* in stored sewage, but rather a temporary increase, which among other reasons might be attributed to breaking up of the colloidal aggregates and bacterial clumps. In activated sludge there is a greater reduction of *B. coli* than can be explained by mere settling of the flocs. The greatest actual reduction takes place when there is a preponderance of ciliates in the

aeration tanks. Similarly, air maintains a predominant flora and fauna (with large numbers of ciliates) in a sprinkling filter, causing a reduction in *B. coli*.

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Bacterial Death Rates in Polluted Waters.—Experiments on the fate of bacteria in polluted waters have been made by C. G. Butterfield at the laboratory of the United States Public Health Service at Cincinnati. Bacterial counts on 45 samples of Ohio River water stored in bottles at 20° C. were compared with similar counts on samples from the Ohio River. A decrease in count occurred at once in the samples from the river. In the bottles, however, a marked initial increase occurred, followed by a decline, which was not nearly so rapid as the decline in the counts on the river samples.

Fifty-nine samples of the Ohio River water were stored in wooden pails subjected to intermittent agitation and diffused daylight, and 73 samples were suspended in glass bottles in the Ohio River at the site of collection. The bacterial death rates in these experiments were variable and did not agree at all with the river death rate. In the case of the pails 29 samples showed an increase and 30 showed a decrease. In the bottles suspended in the river 40 samples showed an increase and 33 a decrease. Experiments were made in an artificial channel 0.8 mile long, fed with Ohio River water. The time of flow was about 48 hours. The death rates found under these conditions were similar to those observed in the river itself. *Journal of Bacteriology*, **16**, 257, Oct., 1928.

Sewage Works Operation

Sewage Works Odors and Their Control[1]

By Morris M. Cohn[2]

If there is any one problem more intimately associated with satisfactory sewage treatment plant operation than that of odor control, there is at least one operator who has not been confronted with it. By all the measures of efficiency, what is a well-operated plant? The operation of sewage works is today a task in human engineering. Production of satisfactory unit efficiencies may satisfy the state departments of health and the turning of a fine effluent into the diluting stream may be a joy forever to the Isaac Walton League, but there is still another social group that must be satisfied if sewage treatment works are to continue to be built and to function. All the fine operation records and stable effluents will not give to residents in the vicinity of plants that peace, comfort and enjoyment of home life to which they are justly entitled. No plant is well-operated which produces and disseminates odors. The higher standards of living are forcing us to come from behind our ambush of operating alibis and to insist on equally high standards of plant operation. With what we already know, and fortified with further knowledge that we can gain if municipalities would but spend for research a few of the pennies expended in odor lawsuits and settlements, the day of civic pride in sewage treatment plants may yet dawn.

Sewage is, at best, a potentially odorous material to handle; odor dangers lie in both the liquid flow and the solid matter that it carries. It is to be expected that odors will develop and be subject to normal conditions of travel and distribution, if great care is not practised in dealing with crude sewage, effluents and residues and with the treatment units through which they pass or in which they are stored.

In a broad sense, odor control consists in preventing, as far as possible, the production of odors and in taking steps to destroy or minimize such odors as do develop, before they are wafted off plant property. Such control can best be effected by practising what I like to call the three c's of odor control—care, cleanliness and chemical treatment. Care and cleanliness are the types of effort that prevent the production of odors; they mean

[1] *Presented on behalf of Mr. Cohn by Harry M. Beaumont, Asst. Engineer, Bureau of Engineering, City of Phila., before the Third Annual Conference, Pennsylvania Sewage Works Association, Harrisburg, Pa., July 16, 1929.*

[2] *Sanitary and Testing Engineer, Dept. of Public Works, Schenectady, N. Y.*

hard work, and do not result in glamorous victory for the striving plant operator. These measures are rank-and-file work and are as much the backbone of the odor control program as the rank and file are the strength of an army. The process of odor prevention and elimination by chemical treatment is newer, attracts the attention and results in improvements that are quickly apparent to even untrained nasal senses. It takes downright patience to prevent odor nuisances by practising care and cleanliness in operation technique but true excellence of plant operation can only come with such efforts. "An ounce of prevention is worth a pound of cure"—yes, and a pound of prevention costs less than an ounce of cure.

The sewage works most difficult to maintain in non-odorous condition, and against which most complaints have been lodged, are those of the Imhoff tank-trickling filter type. Discussion of odor sources and control measures to be taken at such a works will make understandable the value of the three c's of odor control. In a plant of this type, odors may be produced by the trunk sewer, fine screens or bar rack, grit chambers, Imhoff tanks, sludge beds, lagoons, dosing tanks, trickling filters, secondary settling tanks and the material passing through or stored in these treatment devices.

Trunk Sewer

The odor of sewage in trunk sewers may result from the liquid with its dissolved constituents or from the water-borne filth. The odor of fresh raw sewage is of a soapy, slightly musty nature, coupled with odors characteristic of the type of material carried by the sewage flow. Such odors may be of oil, feces, industrial wastes or like material. A septic raw sewage will give off gases of decomposition such as methane, carbon dioxide and hydrogen sulphide.

Certain industrial waste constituents are best excluded from the raw sewage. A steadily increasing demand for the exclusion of gasolines and oils from the sanitary sewers is making itself felt. The dumping of garbage material into toilets by housewives should be discouraged. While flow in an open channel may produce aeration and consequent odor diminution, turbulence in raw sewage is generally to be avoided. Long trunk sewers, coupled with slow, shoal-producing flows result in septic, stale sewage, partially decayed solids and consequent added odor troubles at the treatment works. Proper design of all treatment features is a necessity if the long-suffering plant operator is to succeed in maintaining a fresh-smelling installation. Pumping of sewage has a tendency to result in more finely divided solids in the sewage flow and is beneficial in preventing odors of feces and other easily comminuted material.

A septic raw sewage injects a menacing problem of odor control at the outset of treatment, which grows steadily worse throughout the purification cycle. All efforts should be made to prevent or neutralize such septic

tendencies. Most excellent odor control has been effected on a septic raw sewage by the application of chlorine at some point in the trunk sewer at a distance above the plant site. When applied at a point far enough up in the trunk line, the chlorine may delay bacterial decomposition and septic conditions may never exist in the liquid. If septic action has already started, the chlorine acts directly upon the hydrogen sulphide and results in odor elimination by destruction of this troublesome gas. The writer has accomplished marked odor reductions in the raw sewage by the prechlorination of sewage at a pumping station wet-well some two miles above the treatment works, at rates as low as 2 to 4 p. p. m. of chlorine, while heavier dosages resulted in production of chloro-substitution odors that were noticeable about the Imhoff tanks. Tests indicated that while the hydrogen sulphide content of the sewage was diminished, odor control did not depend on the complete destruction of this gas. Such satisfactory conditions as reduction in biochemical oxygen demand, and the retarding of the tendencies of septic sewage to decompose concrete trunk sewers have been reported by other investigators.

Grit Chambers

Well-designed and well-operated grit chambers should give but little odor trouble. The chamber should, of course, be cleaned at regular intervals and the accumulation of organic solids should be prevented. Care in operation and cleanliness about the protective racks, chambers proper and cleaning mechanism, will do much to keep this treatment unit in non-odorous condition. Grit, if satisfactorily low in organic matter, can be used for fill or may be used as a covering for more odorous trash.

Screening Installations

Screening, or the straining of more or less suspended material from the sewage flow, results in the capturing of a material that presents a vexing problem for the odor control proponent. The screen house, more than any other spot in the treatment plant, requires untiring care in operation and scrupulous cleanliness if odors are to be prevented. The trend toward mechanical screening equipment has done much to keep down odors and to dispose of screenings to storage hoppers or cans without muss or fuss. The screens or racks should be kept clean, the operating floors swept and well-flushed and no debris should be permitted to gather. Stored screenings can be deodorized by means of cresol compounds or chloride of lime. "Phinotas" deodorant has been used successfully. A small quantity of deodorant sprinkled about will do much to raise the morale of the rack or screen attendants.

Screenings can be trenched, plowed under the soil, composted or incinerated. The disposal of screenings in low spots about the plant site produces

obnoxious odors and objectionable breeding-ground for flies and rats. The drying of screenings on open beds is subject to the same objection of odor production. The fact that a treatment plant is located at a safe distance from habitation should be no inducement for the operator to neglect the satisfactory sanitary disposal of this troublesome material. An odor is an odor even if there is no nose to smell it. Perhaps the foulest and most disgusting odors about sewage plants ever observed by the writer have come from accumulations of trash in some handy ravine or borrow pit. The covering of screenings with dried sludge, grit, dirt or other absorbent material, as rapidly as spread, will do much to control the odor emanating from this source.

The writer has had excellent success with the disposal of bar-rack-captured material to the amount of about $^3/_4$ cu. yds. daily, at a plant located but a few hundred feet from a well-populated city street. Winter screenings are stored and shallow-trenched in clayey ground just before all the frost leaves the accumulation in the spring. Summer screenings are transported daily to a plowing field, accumulated in small piles for a week and then thrown into a furrow and covered by plowing. No odors have ever emanated from the trenching or plowing fields. Test borings indicate that the trenched material decomposes in about four years while the plowed material is destroyed, except for an occasional piece of rag, in one year. Chloride of lime, both dry and in milk form, has been used on storage piles awaiting plowing, to prevent odor and fly production during hot summer days. Attempts to interest farmers in screenings as a fertilizer have met with but little success, because of the unclean appearance of the trash. Disposal of screenings to farmers is, of course, an ideal method to remove this odor-producing material from the plant site.

Imhoff Tanks

The operation of Imhoff tanks, without the production of odors, requires the expenditure of much labor and effort. Odors may emanate from the liquid or floating solids in the sedimentation compartments or from the gas vent area. Given a normally fresh sewage and periods of detention that permit of the production of a moderately fresh tank effluent, the liquid flowing through the tanks will produce no marked odors except those of sewage, as discussed above. The sleek of kitchen grease, soap curd and floating debris is susceptible to decomposition, especially under the heat of the sun, and rancid, putrid odors may be produced. Sewage surfaces should be kept well-skimmed of such material; disposal can be made by burying or by dumping into the gas vents and hosing. The presence of scum boards at the ends of the tanks will prevent the blowing of this material into effluent channels, but tank operators object to added scum boards placed near the center of tank lengths because they intercept material and neces-

sitate the dirty skimming process at several points. The construction of skimming tanks for the trapping of this type of troublesome material will do much to prevent odors. Efficient grease trap installations at restaurants and hotels are great aids in plant operation. A breeze is the best friend of the tank attendant, since it piles all sleek up at one end of the tank and makes removal easy.

The ebullition of gas-lifted sludge and the consequent production and transmission of marked odors can be prevented by a routine program of squeegeeing of sedimentation compartment bottom slopes and clearing of slots by means of chains or other home-made contrivances. A clean sedimentation compartment does not belch. The accumulation of solids above the slots in the tanks should be avoided. There is certainly no odor stronger or more disgusting than that given off by floating islands of semi-digested solids.

The shoaling of solids in the inverts of inlet or effluent channels results in anerobic decomposition and the production of hydrogen sulphide gas. Accumulated solids should be flushed from such channels before gas production is noted. The installation of $^1/_4$-in. mesh screens at the effluent weirs of the Schenectady tanks have done much to prevent the shoaling of solids in the effluent channels and odor production from this point. Flow should be reversed often enough to prevent such non-flowing liquors as are present in reversing channels from becoming septic. Such channels may be covered; flow should be as quiescent as possible.

Gas vents are a frequent source of troublesome odors. Violent puffing of digestion gases will carry odors to some distance. Foaming should be prevented, since this phenomenon results in the covering of walks and sedimentation compartments with mats of scum that dry out in the sun and give off the characteristic choky sludge-drying odor in concentrated form. Again, the passage of such foaming solids out of the tanks will result in odors from secondary treatment units. Foaming can be prevented by a well-balanced program of sludge removal, by the drawing of foam through sludge risers, or by mechanical agitation or manual paddling of the fluffy mass to release the entrained gas. Hosing of gas vents will, of necessity, produce odors, especially from thick, leathery and under-digested scum blankets. Hosing is open to the further objection that it stirs up the material in the sludge compartment and sets up convection currents that result in the passage of septic liquid into the sedimentation compartments, with consequent odor production. Covering of gas vents prevents the action of the sun on the scum and is of value in an odor control campaign. The presence of swollen home-brew mash in the gas vents results in a sourish smell. The writer has used a pine-tar deodorant in gas vents with some measure of success during hosing operations of semi-digested scum.

The process of sludge digestion results in the liquefication and gasification

of a portion of the organic solids. The emanation of these gases results in odor nuisances. The collection of gas from Imhoff tanks, as from separate sludge digestion tanks, bids fair to be a most progressive step in the control of odors. Reports indicate that the collection and burning of such gases has resulted in complete removal of the causes of serious odor complaints.

To me, the tank attendant who knows how to keep his units in scrupulously clean condition is an artist. Give me the man who keeps all concrete surfaces broomed and well-flushed, all sludge channels washed after each drawing and who knows that water under pressure applied just above the surface of the sewage line in the tanks and channels will prevent the formation of that gelatinous growth with the persistent odor that cannot be washed off the hands. The accumulation of bits of skimmings and screen-washings about tanks is inexcusable.

Care and cleanliness will do much to maintain Imhoff tanks in non-odorous condition, given a fresh sewage and flow conditions through the tanks that do not result in depletions of dissolved oxygen. Where such conditions do not exist, the use of chlorine applied in the raw sewage, either in the trunk sewer as described above, or at the inlet to the tanks, can be depended upon to effect remarkable odor control. At Schenectady, the writer has controlled odors in the Imhoff tanks by prechlorination of the raw sewage at the tank inlet at rates of 4 p. p. m. and over. At rates of 6 p. p. m. and over the tanks gave off a clean chloro-substitution odor that was apparent to both laymen and sewage experts who visited the plant. The tanks took on a grey color during the morning and a coppery brown tinge in the afternoon. Residual chlorine was not present in the effluent or at any point in the tanks and some hydrogen sulphide was found by repeated tests to be present in the tank effluent. It would appear that odor control does not require the neutralization of all hydrogen sulphide in the sewage. Experience at Schenectady this year has indicated that tank odors are most marked during the early morning hours and the evening hours just prior to the fall of darkness. The prechlorination of the crude sewage flow at these hours is resulting in excellent odor control at the tanks. Without a doubt, the practice of the three c's will control odors from Imhoff tanks.

Sludge Beds

It may be putting it too strongly to say "take care of your Imhoff tanks and your sludge beds will care for themselves," but in a sense it is true. The odor of the air-drying of well-digested Imhoff sludge is not objectionable and does not carry to any great distance.

The placing of poorly-digested sludge on open beds is the gravest social error listed in the sewage works etiquette book. That little difference between a good and a not-so-good sludge may give you a chance to play the

rôle of a star witness in some very interesting suits in which the complainants will testify that "certain vile and disgusting odors did injure the health and happiness of said complainants' family."

Seriously, the trend toward covered sludge beds is an excellent step in sewage-plant odor control and will do much to raise the status of the art of treatment.

Air-dried sludge can be disposed of by use as a fill for low land, may be plowed under the soil or may be stored and sold as a fertilizer. When accumulated about the plant site it has a tendency to give off some odors, especially after being wet down by a summer rain. The writer is a firm believer in the self-evident principle, that what is off plant property does not create odors at the plant. By an intensive program of sales education, the farmers in the vicinity of the Schenectady plant have been so completely "sold" on the value of sludge as a fertilizer, that every particle of the material produced during the past four years has been sold, the farmers having scraped and fine-tooth-combed the storage piles and even raked the sludge beds in search for more. There is no old sludge at Schenectady to give off odors. Try that on *your* farmers in your spare moments.

Lagoons

The odor emanating from sludge lagoons is similar to that discussed under sludge beds. The lagooning of well-digested sludge at a plant where sufficient drying space is not available is excusable, but the use of a ravine for the disposal of poorly digested material, in order to clear tanks, cannot be classed as efficient operation. Odors will result that may be difficult to control. The use of strong deodorants may be of value around lagoons or sludge dumping grounds. Satisfactory facilities should be provided for the drainage of excess water from the lagoon area.

Dosing Tanks

Since dosing tanks act as the concentration points for tank effluents, it is natural that they should be subject to much the same odors as the Imhoff tanks themselves; odor control measures taken in the tanks will be reflected in decreased odors from the dosing tanks. Thus, a fresh clarified sewage, containing a minimum of suspended solids, will produce but slight odors during the cascading action it receives in its passage over weirs and steps and during the turbulence it undergoes when the siphonic or other dosing apparatus goes into action. In fact, the aeration the liquid receives here may be of distinct value in reducing odors emanating from filters to which it is applied.

But, given a tank effluent containing appreciable amounts of hydrogen sulphide, the dosing tank may become the worst odor-producing unit in the plant. Under such conditions, the application of chlorine in such

amounts as to produce non-odorous conditions in the tanks will result in the emanation of but a chlorinous odor at this point. At Schenectady, application of chlorine to raw sewage at the inlet to the Imhoffs, at rates from 4 p. p. m. to 6 p. p. m., completely destroys hydrogen sulphide emanation from the dosing tanks during the trying hours of early evening. Under adverse conditions, the covering of dosing tanks may be of advantage in preventing odor dispersion at this point.

Dosing tanks must be kept clear of putrescible solids that may gasify and rob the liquid of its valuable oxygen content. The development of gelatinous film on the concrete surfaces should be prevented by regular flushing.

Reports indicate that the mixing of normal sedimentation tank effluent with a smaller portion of the effluent from an auxiliary activated sludge plant results in a liquid that is fresh and non-odorous.

Trickling Filters

Trickling filters have been said to look nice and to smell not so nice. Perhaps that reputation was well deserved. Filters may produce odors from the sewage spray thrown by the nozzles and that resulting from the impinging of the liquid on the surface stone and also from the prolific gelatinous organic growth that develops on the stone. The former odor is that of hydrogen sulphide, if septic, or soapy and slightly musty if non-septic in nature. The gelatinous growth gives off odors of a swampy, sea-weedy character. The drying action of the sun on a heavy film and its worm population results in odors that are marked and are reminiscent of decaying shell-fish.

Care and cleanliness in operation will tend to abate some filter odors. The passage of solids out of the tanks results in deposits on the filters and the odor of decay about the plant. Sludging up of the filter stone is to be avoided since the deposited solids will give off musty odors and objectionable surface pooling will most certainly result. A pooling filter cannot be fresh. The flooding of filters for psychoda control results in the washing of large quantities of fly and worm life out of the beds. This material, if allowed to dry on walks or grass and in gutters, after the drawing down of the beds, will result in vile odors that travel to great distances.

Application of chlorine at the most advantageous point can be depended on to control odors from trickling filters, both from the applied sewage and from the beds themselves. The application of chlorine to the raw sewage, either in the trunk sewer above the plant or at the tank inlet will result in a non-septic clarified sewage, low in hydrogen sulphide, which will give off no disagreeable odors when sprayed from stationary nozzles. On the other hand, it is impracticable to prechlorinate raw sewage sufficiently to deodorize the gelatinous film on the surface media, and complete destruction of filter odors cannot come without effecting such deodorization. At Schenec-

tady, original investigations carried out in 1925 indicated that the application of chlorine to tank effluent in the siphonic chambers at rates as low as 4 p. p. m. resulted in a marked change in the odor conditions of the sewage applied to the treated filter units. At rates of 6 to 8 p. p. m. a clean chlorosubstitution odor replaced the usual sewage odor from the beds. No effect was noted on the stone film. At rates above 10 p. p. m. distinct chlorine residuals were noted in sewage collected at the nozzles and the chlorine bleached out the black growth on the stone and on the nozzle spindles and domes. Within a few days, the film sloughed off the stone and passed into the beds, producing the phenomenon of unloading. The beds looked like new units. No pooling was noted and the beds gave off no odors even when allowed to dry out under the sun's rays. In a regular program of filter odor control, heavy chlorination to remove surface film could be practised at very infrequent intervals, and applications of low chlorine dosages for deodorization of the applied liquid could be used only during seasons of the year or periods of the day when conditions of tank effluent or atmosphere indicated that odor control was necessary.

Secondary Settling Tanks

Secondary settling tanks may be the source of troublesome odors. The accumulation of excessive amounts of floating scum must be prevented. The character of this material, as well as the sludge, necessitates care in tank manipulation. The presence of large quantities of decomposable organic matter in the filter effluent results in a troublesome deposit in these secondary tanks. Great success has been reported with the digestion of sludge from such units in Imhoff tanks and separate sludge digestion tanks. Care and cleanliness in operation should prevent the production of nuisances in these final treatment devices.

Conclusion

We have seen the sources of possible odors and the known methods of preventing their production and controlling their escape and dispersion. The plant operator should fully understand the type of wind and atmospheric conditions that are most unfavorable for the odor campaigner, and should be doubly careful during such periods. Complete records of atmospheric temperatures and humidity and wind direction and velocity should be maintained by the plant operator. The connection between some of the cleanliness and care suggestions I have given and odor control may not be obvious, but psychologically they play an important rôle in such work. Many of the "gruesome" odors reported by complainants against sewage works are but figments of the imagination. I said at the outset that a certain social group must be satisfied with plant operation and that excellent efficiencies and stable effluents will act as no balm for the injured feel-

ings of the old residents of a section in which a treatment plant is located. Much neighborhood antagonism disappears when a plant is kept clean and orderly. Green grass, flower beds, shrubs, well-kept roads and a generous use of paint and brush dull those over-keen senses of smell that are present in the imagination. This accomplished, the problem of odor control is reduced to its technical aspects and the wide-awake sewage works operator can take up his instruments of warfare against odors as they are and not as they are imagined. That is sufficient battle for the most astute. The results of victory are glory enough for the most successful.

British Methods of Sewage Analysis.—The British Ministry of Health has issued a report of a committee representing various public bodies which was appointed some time ago to discuss the question of technique in carrying out chemical analyses of sewage and sewage effluents.

The report (price 2s. 6d. (63 cents) H. M. Stationery Office) designed to assist those who are engaged in testing the purity of effluents from sewage disposal works and of rivers, should contribute materially towards securing greater uniformity in the technique of the various tests. It deals with:

1. Methods for carrying out tests for sewage and sewage effluents and methods of expressing results.
2. Tests to be included in all analyses.
3. Tests appropriate for use at small sewage works.

The Royal Commission on Sewage Disposal, which sat from 1898–1915, did a large amount of work on methods of analysis, and in suggesting the best methods which might be adopted, the present committee has built upon that work. One of the members of the committee, Dr. McGowan, was the Chemist to the Royal Commission. *The Surveyor*, **76,** 322, Oct. 11, 1929.

Distinctive Characteristics of the Indianapolis Sewage Treatment Plant[1]

BY CHARLES H. HURD[2]

The Indianapolis Sewage Treatment Plant has some distinguishing features. Nearly every city has sewage which is characteristic of the city itself. If it is primarily a residential city, you might expect the usual sanitary and domestic sewage, but in the matter of treatment even this sewage may vary considerably, depending to some extent on the character of the water supply.

Indianapolis sewage in treatment reflects the hardness of the water and particularly the trade wastes. The industrial plants of Indianapolis which contribute to the sewage are for the most part packing enterprises. Some of the largest fruit and vegetable packing plants in the world are located here and our records show that more animals are slaughtered per unit of population than in any other of the principal American cities.

As a result of the numerous packing plants and perhaps a more careful supervision as to the waste of water, Indianapolis has a relatively strong sewage. Compared with Chicago and Milwaukee, the sewage carries about twice the organic solids of Chicago sewage and has about one-and-a-half times the solids of Milwaukee sewage.

In the design of sewage treatment works there are usually three contributing factors, first, the strength and character of the sewage, second, the variability of the flow and the concentration, and third, the completeness of the purification required. The latter is generally controlled by the dilution effected or by the dissolved oxygen contained in the body of water or the watercourse into which the effluent is to be discharged.

All three of these factors are present in Indianapolis, and each influenced the design and materially affects the operation of the plant. The sewage is unusually strong. The fluctuation is very marked both as to quantity and concentration on account of the combined sanitary and storm system. The requirements are optimum during low flow and when dissolved oxygen in the river water is depleted.

To meet these conditions the plant was designed to give complete treatment during summer and periods of low available oxygen in the river and partial treatment throughout the entire year.

Combination System of Preliminary Treatment

For the clarification or partial treatment, plain settling was considered and also the use of fine screens. Most fine screens have the disadvantage

[1] *Notes from a talk at the Indianapolis Meeting of the Central States Sewage Works Association, June 20, 1929.*

[2] *Consulting Engineer, Indianapolis, Indiana.*

of having short life and are more or less troublesome in operation. Plain settling tanks, mechanically operated, for large quantities of sewage with a wide range of concentration, are expensive. It occurred to us that a combination of the two would meet the condition of low initial cost and high operating efficiency, and this arrangement for Indianapolis seems to be ideal.

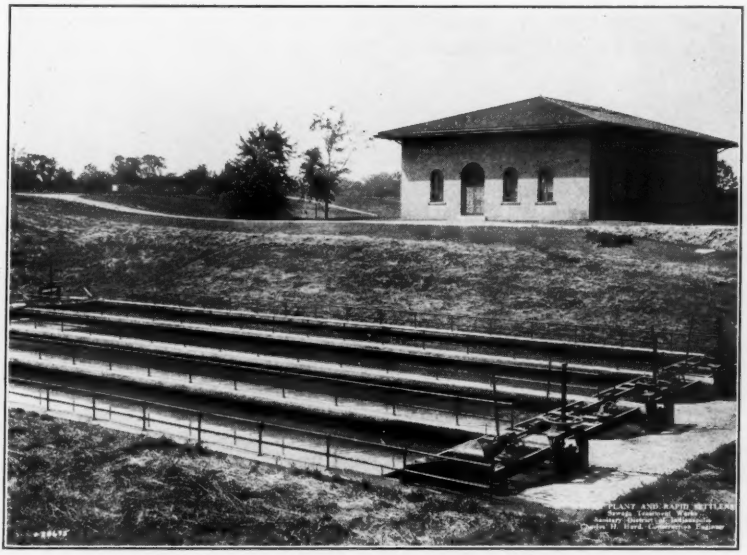

FIG. 1.—Primary Settling Tanks and Screening Plant, Indianapolis Treatment Works.

The theory of the operation of the Indianapolis screens is different from that of most screen installations in that the partially clarified liquid is taken away from the solids instead of attempting to remove the solids and colloidal matter from the liquid. The screens are set in four batteries of three units each. The individual screens are constructed of bronze, six feet in diameter and eight feet long with $^1/_{16}$-in. slotted perforations. The screens are provided with a backwashing system, which consists of stationary deflecting blades placed inside of each unit at the point where the screen in its rotation leaves the liquid. This method instead of the use of the usual brushes is very effective in freeing the solids from the screens. After about 75 per cent of the clarified liquid has been removed, approximately 25 per cent passing out over the weirs at the end of each screen, the residual liquid which contains all the solids retained by the screens flows to the mechanical clarifiers for final separation.

The mechanical clarifiers or rapid settlers are really long rectangular tanks equipped with traveling sweeps which convey the solids in the form of sludge into cones near the inlets, from which it is pumped to digestion pits for disposal. The outstanding feature of the rapid settlers is the high efficiency, with short subsidence period, which is less than twenty minutes. The short period is the result of high concentration effected by the screens.

It has been demonstrated that high efficiency cannot be expected in the operation of fine screens or primary settling, with this process, if the sewage

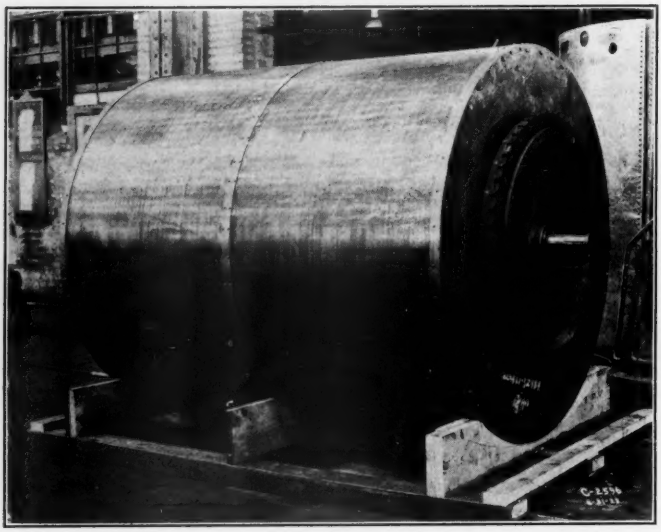

FIG. 2.—Fine Screen Drum, Indianapolis Treatment Works.

has been previously agitated by centrifugal pumps. It has also been shown that the removal is not proportionate to the size of openings in the screen providing the sewage has not been agitated. The percentage of removal of organic solids with the clarification system is unusually high and it also has a great range in treating capacity to take care of storm flows. During the year 1928 the removal by clarifiers was 36 per cent of the total suspended solids contained in the sewage.

The capacity of the screens and primary clarifiers is 120 m. g. d. or about $2^1/_2$ times the average dry weather flow. The larger capacity was provided so that a considerable amount of storm water can be given clarification treatment in addition to pretreatment for the activated process.

Activated Sludge Treatment

The activated sludge process is well adapted for Indianapolis, on account of the city's highly concentrated sewage and the efficiency required during summer conditions. As stated, at times the river is practically depleted of oxygen and under these conditions the treatment should be such as to minimize putrefaction. In fact, with the dissolved oxygen contained in the activated effluent the condition of the river should be improved. The packing house waste in Indianapolis sewage was one of the influencing

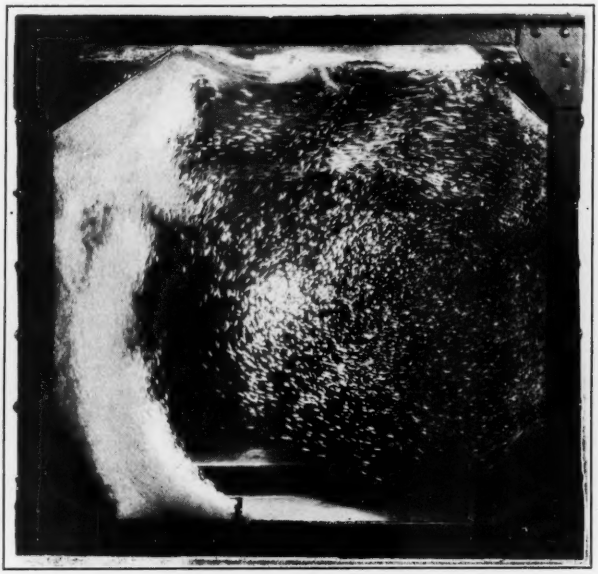

FIG. 3.—Original Glass Tank Used for Experimental Development of the Deflecting Baffle System for Spiral Circulation, 1920–1922, Indianapolis Treatment Works.

factors in determining upon the treatment process. Our experience with packing house wastes is that the wastes from slaughtering of animals and meat packing are susceptible to activated sludge treatment but that such wastes add materially to the organic load. The treatment of vegetable wastes has proved at times to be more difficult with the development of types of organisms which cause bulking and are otherwise troublesome.

The characteristic feature of the Indianapolis activated plant is the spiral circulation. The deflecting baffle system of spiral circulation in activated sludge treatment was developed in Indianapolis, and the name "spiral

circulation" was first used here. This method has been adopted without change in nearly all of the new activated plants constructed since the completion of the Indianapolis sewage works.

May I add just a word about the design of spiral circulation. The effectiveness of this method, in addition to the use of deflecting baffles, depends on the arrangement of the air diffusers. The whole design might differ with unscreened and unsettled sewage. The arrangement of diffusers depends upon whether it is necessary to sweep the bottom with high velocity to prevent settling of the heavier solids or whether air might be used more effectively to give more complete diffusion.

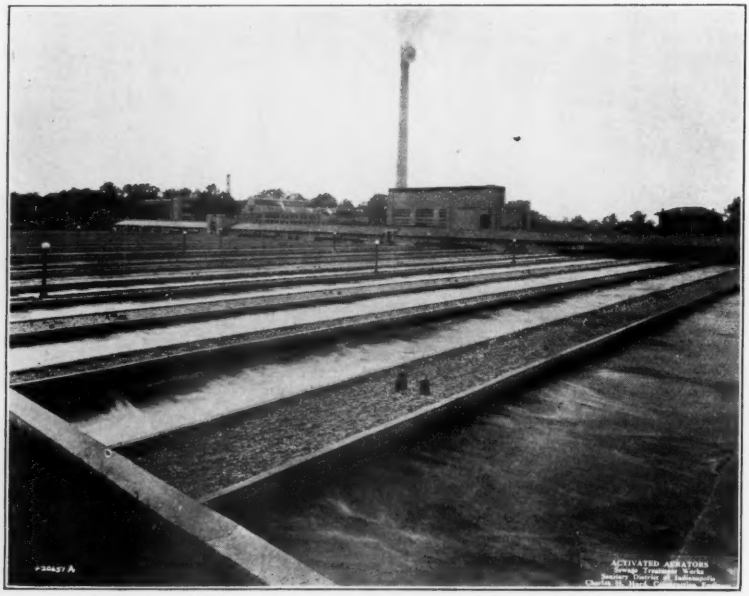

FIG. 4.—View of Aeration Tanks, Indianapolis Treatment Works.

We have recently completed a design for a 25 per cent addition to the Indianapolis activated plant. The plant was only intended to have a capacity for 1930 condition and 1930 is almost here. In this new design we have brought the diffusers even more to the center of the tank, which is one of the original and important features of spiral flow as distinguished from other systems with air eccentrically applied. In addition to this we have provided diffusers which are set in a series of "V"-shaped formations to break up uniformity and to prevent any possibility of short circuiting.

In our new design we have also made some improvement in the final settling tanks for activated sludge. It is realized that this part of the plant performs one of the most important functions. The capacity of the original tanks was too small, not that the tanks themselves were too small —there is some advantage in the use of small tanks, but we did not have sufficient settling period.

In the treatment of sewage, especially in the larger plants, the activated sludge process has many advantages. Even with the smaller plants, with provision for digestion of the activated sludge, we believe this method of sewage treatment will be more universally used. It is unquestionably one of the cleanest and most sanitary processes and its cost in most cases when complete treatment is required is economically within the reach of almost any community.

Aeration and Agitation of Sewage.—A paper, presented by Mr. W. H. Makepeace of Stoke-on-Trent, England, at the 1928 meeting of the Association of Managers of Sewage Works, discusses experiences with the activated sludge process of sewage treatment.

It is generally admitted that compressed air is mechanically inefficient for mixing sewage. The spiral-flow method is too perfect in that a good deal of quiescence is found in the center of the core. When mechanical mixing is used with diffused air the amount of air necessary for good oxidation is materially reduced. At the Hanley (England) plant in 1923 the air consumption was 2 cu. ft. per gallon using diffused air and in 1928 this had been reduced to 0.7 cu. ft. per gallon using mechanical agitation in conjunction with diffused air.

Whether mechanical aeration alone is practical was tried by using propellers fixed at a 30° angle to the water surface. A very high mechanical efficiency was obtained but aeration was insufficient. The experiment was repeated using the propellers and in addition 3-ft. diffusers were placed 40 ft. apart and air was blown into the sewage at various depths, ranging from 6 inches at the surface, to 12 inches, two feet, three feet and four feet, respectively. The tank depth was four feet ten inches. Results indicated that greater purification was obtained as the depth of the diffusers was increased.

An experiment was made aerating with diffused air for the first period followed by mechanical aeration. The efficiency was unimpaired and the process was more economical.

In the discussion it was suggested that perhaps mechanical aeration followed by diffused air would be better. Mr. Makepeace said he believed purification was obtained more quickly and completely by using the compressed air first, then following with mechanical mixing. *Proceedings of the Association of Managers of Sewage Disposal Works* (England), pp. 96–108, 1928.

Sewerage and Sewage Treatment in Illinois[1]

BY HARRY F. FERGUSON[2]

Illinois was originally a rich prairie agricultural state without industries. For many years there has been a rapid industrial development, partly because of natural mineral resources, and partly because of the strategic location of the state on both the Great Lakes and Mississippi drainage basins. The industrial development has created problems in the disposal of wastes from industries founded upon agricultural activities rather than from those developed upon the mineral resources. These major industrial-waste-treatment problems have been with packing plant, corn products, cannery and milk wastes. Possibly with future utilization of corn-stalks for wall board, paper, etc., there may be another waste-treatment problem created by an industry founded upon agriculture.

Sewer Systems.—Of the 1113 cities, villages and incorporated towns in Illinois 508 have public water supplies, and 411 have some form of public sewer system. There are some cities that have not even installed water-supply systems but do have some drains installed for ground drainage, to which a few cesspool and septic-tank overflows have been connected. Therefore, it is difficult to state just what is and what is not a sewer system. Of the 411 sewer systems considered in this paper 154 were installed as combined storm and sanitary sewers, 142 as separate sanitary sewers and 115 as mixed systems of sewers and drain tiles which are sufficiently extensive to be classed as public sewer systems. Storm sewers have not been considered if they carry no sewage.

Combined vs. Separate Sewers.—The question of combined versus separate systems of sewers has been a debatable one in Illinois as in other states. Some engineers have favored combined sewers entirely. A few have been strong advocates of separate systems of sewers, and others have considered that each installation must be decided independently upon local conditions. In the congested area around Chicago, where sewage treatment is a critical problem, there are 52 cities with combined sewers, and only 19 with separate systems of sewers. If these cities were to reconstruct their sewerage projects there is no doubt but that, with present knowledge and experience, practically all would install separate systems of sewers.

Population Loads and Sewage Flows.—Sewage-treatment works are

[1] *Read at Second Annual Meeting Central States Sewage Works Association, Indianapolis, Ind., June 20, 1929. This paper is based upon a more complete detailed study of sewage treatment in Illinois by Engineers A. F. Dappert, C. E. Schwob and H. F. Ferguson, Division of Sanitary Engineering, Illinois Department of Public Health. Copies of a pamphlet giving a detailed table of sewage-treatment works in Illinois can be obtained by request to the author.*

[2] *Chief Sanitary Engineer, Illinois Department of Public Health.*

designed on the basis of population and volume loads. Of 131 sewage-treatment works in Illinois, 59 receive sewage flows equal to or greater than 100 gallons per capita per day, 61 receive flows between 50 and 100 gallons per capita per day, and 11 receive flows less than 50 gallons per capita per day. In each case the per capita flow has been obtained by using the entire population of the cities. Sewage flows for the smaller cities were taken almost entirely as equivalent to the water consumption, because of the lack of direct measurements.

The present standard used in Illinois in reviewing plans is a flow of 100 gallons per capita per day from sanitary sewer systems, with, of course, allowance for greater hourly rates. For combined sewer systems, the storm flow that must be handled by sewage-treatment works before overflow devices are used or automatically come into service depends upon the size, character and use of the streams below the outlets and the tributary drainage areas of the streams above the outlets. Intercepting and outlet sewers for combined systems have been built to handle from 2 to 25 times the average dry-weather flows, but treatment works have been built to handle up to only about 4 times the average dry-weather flows. In general, only some of the units of complete treatment works, such as settling tanks, have been designed to handle more than two times the dry-weather flow.

TABLE I

SEWAGE-TREATMENT PLANTS IN ILLINOIS BY YEARS

Year	Plants with Secondary Units Treating Combined Sewage	Plants with Secondary Units Treating Sanitary Sewage	Plants with Primary Units Only Treating Combined Sewage	Plants with Primary Units Only Treating Sanitary Sewage	Total Number of Plants of All Types
1892	0	1	0	0	1
1897	0	1	0	1	2
1902	0	2	2	2	6
1907	1	6	4	8	19
1912	3	9	9	21	42
1917	8	22	15	39	84
1922	18	32	17	46	113
1927	32	42	21	64	159

Growth and Development of Sewage-Treatment Works.—One of the first, if not the first, sewage-treatment works to be constructed in Illinois was at Pullman, now a part of Chicago. The oldest treatment works, according to the files of the State Health Department, was built in 1892 at Dwight. This plant comprised merely a small bed of cinders which served as a roughing filter. Within a short time the cinder filter became clogged. The second works was constructed at Macomb in 1894 and comprised a septic tank. Table I brings out the slow growth and development of sewage-treatment works between 1892 and 1902. The installation of sewage works began to increase about 1904 and it has since continued at a

rather uniform rate except as retarded during the war period. The present indications are that the rate of installation will be greater during the next ten years than in any past decade. The volume increase will be brought about by the works of the Sanitary District of Chicago and other sanitary districts installed in Illinois under a separate sanitary district law. The increase in number of plants will be brought about by installations by smaller cities because of activities of downstream property owners affected by stream pollution. The functioning of a new stream-pollution law will also stimulate the construction of new plants.

Table II shows the rate of increase of sewage-treatment plants with regard to population rather than to number of units. Table I shows that there has been a much greater increase in the number of sewage-treatment plants treating sewage from separate sanitary sewers than in the number of those treating sewage from combined sewers, but Table II indicates that there has been a greater increase in the population handled by plants receiving sewage from combined systems as compared with those receiving

TABLE II

1927 POPULATIONS SERVED BY SEWAGE-TREATMENT PLANTS IN ILLINOIS BY YEARS

Year	Plants with Secondary Units Treating Combined Sewage	Plants with Secondary Units Treating Sanitary Sewage	Plants with Primary Units Only Treating Combined Sewage	Plants with Primary Units Only Treating Sanitary Sewage	Total Population Served by Plants of All Types
1892	0	2,500	0	0	2,500
1897	0	2,500	0	6,000	8,500
1902	0	4,500	14,000	11,400	29,900
1907	0	14,000	21,000	28,900	63,900
1912	9,300	19,200	48,500	53,900	130,900
1917	14,300	64,500	69,900	84,950	233,650
1922	143,568	100,490	72,000	98,750	414,808
1927	360,639	151,790	84,624	127,375	724,428

sewage from separate sanitary sewers, because of the inclusion of the Calumet and Des Plaines River plants of the Sanitary District of Chicago. The north and west side plants of that district had not been placed in service when the statistical studies for Tables I and II were made.

In 1917 only 34 per cent of the population tributary to sewage-treatment works were tributary to works employing secondary treatment. This increased to 59 per cent by 1922 and 71 per cent by the end of 1927 when the statistical summary was made. A new statistical study and summary will be made during 1930 and thereafter it is hoped to revise the data annually.

The distribution of sewage-treatment plants by population groups is brought out in Table III. With the completion of sewage-treatment works proposed or under construction at Rockford and Peoria, four out of the five largest cities in Illinois will have sewage-treatment works. It is rather

unlikely that East St. Louis, the fifth city in that group, will have treatment works for many years because of the dilution afforded by Mississippi River and the absence of waterworks intakes for many miles downstream.

TABLE III

NUMBER OF TREATMENT PLANTS IN CITIES OF STATED POPULATIONS

	0–1000	1000–2500	2500–5000	5000–10,000	10,000–25,000	25,000–50,000	Over 50,000
Plants with secondary units treating combined sewage	8	7	9	3	0	3	2
Plants with secondary units treating sanitary sewage	5	9	16	7	1	4	0
Plants with primary units only treating combined sewage	3	3	5	3	7	0	0
Plants with primary units only treating sanitary sewage	3	22	23	12	1	2	0
Total plants of all types	19	41	53	25	9	9	2
Number of cities in Illinois	712	229	81	47	27	12	5
Ratio of cities with plants to total cities	2.7%	17.9%	65.5%	53.2%	33.3%	75%	40%

Tables IV and V bring out interesting information as to the types of sewage works that have been installed during different years. The roughing filter and grit chamber are classified in Table IV as primary units for they were actually used for that purpose. Grit chambers that are used as pretreatment devices especially on combined sewer systems have not been included in the tables.

TABLE IV

PRIMARY TREATMENT UNITS

Type Primary Treatment	Date of First Installation	Number Installed				Date of Last Installation	Total Number of Installations, 1927
		1890–1900	1900–1910	1910–1920	1920–1927		
Roughing filter	1892	1	0	1	0	1917	2
Septic tank	1894	3	19	40	10	1924	72
Grit chamber	1898	1	0	0	0	1898	1
Imhoff tank	1907	0	1	30	43	1927	74
Separate sediment and sludge digestion	1921	0	0	0	10	1927	10
Activated sludge	1922	0	0	0	4	1927	4

According to Table IV the septic tank reached its greatest popularity during 1910 to 1920 and then was superseded during the next period by the

two-story or Imhoff tank. The Imhoff tank and sprinkling-filter plants are now receiving competition from separate sludge digestion and activated-sludge plants, and when the statistical summary is made in 1930 it is expected that another interesting phase of development will stand out noticeably in the statistical tables because of these two types of units.

Another interesting fact brought out in Table V is the lack of popularity of the contact filter in Illinois. The intermittent sand filter proved more popular, although not so much so as in some other states. Since 1920 trickling filters have supplanted sand filters because of the lesser areas required and the lower costs.

TABLE V

SECONDARY TREATMENT UNITS

Type Secondary Treatment	Date of First Installation	Number Installed				Date of Last Installation	Total Number, 1927
		1890–1900	1900–1910	1910–1920	1920–1927		
Roughing filter	1914	0	0	2	0	1914	2
Sand filter	1898	1	3	15	6	1926	25
Trickling filter	1904	0	2	9	24	1927	35
Contact filter	1906	0	1	1	0	1917	2
Secondary settling	1915	0	0	2	14	1927	16
Chlorination	1913	0	0	1	4	1926	5
Activated sludge	1922	0	0	0	4	1927	4

Design Duplicated.—There has been a tendency in Illinois, as probably in other states, to play "follow the leader" in the design and installation of sewage-treatment works. A number of engineers, including generally those of lesser experience in sewage treatment and with limited opportunity to investigate sewage works elsewhere in the United States or abroad, have been inclined to keep within the well-beaten track of approved design. Thus the ideas of one person can be traced through more than one installation. Although this duplication has had its drawbacks, it has perhaps proved somewhat safer for the cities concerned than if each engineer had tried to carry out his own ideas or theories without opportunity to test them out before building full-scale sewage works. In this respect the Division of Engineering of the Illinois Department of Public Health, since its establishment in 1915 when it began to review plans for sewage-treatment works, has endeavored to give engineers great freedom and latitude in their design, especially those engineers who were proficient in the science of sewage treatment. At practically no time has approval been withheld from any plan involving new features unless there was good evidence or sufficient theoretical data to indicate that those new features probably would not function properly.

Installation Funds Too Limited.—The installation and maintenance of sewage-treatment works have reflected the fact that a municipality is usually less willing to spend money for sewage-treatment works than for

any municipal project. This fact is frequently due to false economy in design and inadequate estimation of future requirements. Some engineers have been too willing to agree with municipalities on cheap, inadequate installations which have not produced results, commensurate with the limited funds required to build them. The increasing complaints, injunction proceedings, and suits for damages arising out of the operation or failure to operate sewage-treatment works supply the evidence for this conclusion.

Sanitary Districts.—The adoption of the Illinois Sanitary District Law of 1917[1] by 22 cities in Illinois, including 3 of the 5 largest cities, is an indication of the increasing realization by city officials and taxpayers of the legal and moral responsibilities for the treatment and sanitary disposal of their sewage. This increasing civic consciousness and the application of the Golden Rule toward land owners downstream from cities is also noticeable among cities in Illinois that handle adequately their sewage-treatment works problems without the necessity of forming sanitary districts.

The Sanitary District of Chicago, which now has a sewage-treatment works program under way as scheduled with the War Department, comprises roughly one-half the population of the state. One-fifth of the other half of the state population is included in sanitary districts organized under the 1917 law. This makes, including the North Shore Sanitary District, which borders on Lake Michigan and extends from the north boundary of the Sanitary District of Chicago to the Illinois-Wisconsin line, nearly two-thirds of the entire population of the State, included in sanitary districts that have been established for the treatment and sanitary disposal of sewage.

Screens.—A detailed tabulation of Illinois sewage-treatment works (which is not included in this paper) shows that one fine screen and 30 coarse-bar screens have been installed. Of the coarse-bar screens 18 are at plants treating combined sewage and 12 at plants treating sanitary sewage. Nine of the bar screens are used in conjunction with grit chambers and pumps, 5 with grit chambers and without pumps, and 9 are at plants without either pumps or grit chambers. The opening width ranges from $^5/_8$ to $2^1/_2$ inches, and the inclination from 30 to 90 degrees.

Grit Chambers.—There are grit chambers at 21 plants, of which 4 maintain average velocities of 60 feet per minute or more, and the other 17 maintain average velocities of less than 60 feet per minute. The computed theoretical velocities range from a low of 0.41 foot per minute to 102 feet per minute. Of the grit chambers which provide velocities less than 60 feet per minute one provides a velocity between 50 and 60 feet per minute, one between 40 and 50 feet per minute, 2 between 20 and 30 feet per minute, 2 between 10 and 20 feet per minute, 8 between 1 and 10 feet per minute, and 3 less than 1 foot per minute.

[1] Copy can be obtained upon request to the author.

The detention periods of the existing grit chambers vary from 0.3 to 53 minutes, of which 6 are between 40 and 80 seconds, 11 exceed 80 seconds, and 5 are less than 40 seconds.

Grit storage provided varies from 0.0036 to 0.435 cubic foot per capita.

It is apparent that the majority of grit chambers in use in this state are operating with too slow velocities, a condition which must be attributed to error in design.

Pumps.—Centrifugal pumps are almost universally used for sewage. Centrifugal and other pumps are used for sludge. Twenty-eight of 159 sewage plants use pumps, of which 16 operate on raw sewage and 12 pump settling tank effluents to dosing tanks.

Flow Measurements.—Only 7 of the 159 plants have flow-measurement devices.

Imhoff Tanks.—The settling compartment capacities of Imhoff tanks range from 1.5 to 3590 gallons per capita based upon present population loadings. Of the 64 tanks for which data are available, 34 have settling capacities that are regarded as inadequate. Some of this inadequacy has been caused by faulty design and some by the failure of cities to add units as populations increased. Settling capacities of the Imhoff tanks are given in Table VI.

TABLE VI

NUMBER OF IMHOFF TANKS WITH SETTLING CAPACITIES AS STATED

Type Sewage	Gallons per Capita 0–5	5–10	10–15	15–20	20–25	Over 25
Tanks treating combined sewage	3	7	6	1	5	5
Tanks treating sanitary sewage	3	11	13	3	2	5

If the critical velocity in settling compartments be estimated at about 1.6 feet per minute, our data indicate that 14 of the 63 tanks studied have velocities in excess of the critical rate.

The sludge storage capacities in cubic feet per capita are given in Table VII.

TABLE VII

NUMBER OF IMHOFF TANKS WITH SLUDGE CAPACITIES AS STATED

Type Sewage	Cubic Feet per Capita 0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	Over 3.0
Imhoff tanks treating combined sewage	2	2	3	4	3	6	6
Imhoff tanks treating sanitary sewage	1	5	9	5	1	4	13

Twenty of the 26 tanks receiving combined sewage, and 15 of the 38 plants receiving only sanitary sewage are considered as having inadequate sludge-storage and digestion capacities.

Septic Tanks.—The settling and sludge capacities of the septic tanks are given in Table VIII.

TABLE VIII

NUMBER OF SEPTIC TANKS WITH SETTLING AND SLUDGE CAPACITIES AS STATED

Type Sewage	Settling Capacities—Gallons per Capita 0–10	10–20	20–30	30–40	40–50	50–60	Over 60
Tanks treating combined sewage	2	3	3	0	0	1	1
Tanks treating sanitary sewage	4	17	8	2	4	1	4
	Sludge Capacities—Cubic Feet per Capita 0–1	1–2	2–2.5	2.5–3	3–4	4–5	Over 5
Tanks treating combined sewage	3	4	0	0	1	0	1
Tanks treating sanitary sewage	14	13	3	2	3	1	2

Sludge Beds.—Of 159 sewage plants, 74 have sludge beds which have areas ranging from 0.07 to 32 square feet per capita, based upon present populations.

Trickling Filters.—The number of trickling and intermittent sand filters with population and volume loadings are given in Tables IX and X.

TABLE IX

NUMBER OF TRICKLING FILTER INSTALLATIONS WITH LOADINGS AS STATED

Type Sewage	Population Loading per Acre One Foot Deep 0–1000	1000–2000	2000–2500	2500–3000	3000–3500	3500–4000	Over 4000
Plants treating combined sewage	1	1	4	3	2	0	0
Plants treating sanitary sewage	1	4	1	2	0	2	5

Secondary Settling Tanks.—Only 15 of the 33 plants having trickling filters have secondary settling tanks.

TABLE X

NUMBER OF SAND FILTER INSTALLATIONS WITH RATES OF FILTRATIONS AS STATED

Type Sewage	Rate of Filtration—Gallons per Acre per Day 0–65,000	65,000–100,000	100,000–150,000	150,000–200,000	Over 200,000
Sand filters treating combined sewage	0	0	1	0	3
Sand filters treating sanitary sewage	2	1	1	1	10

Plants of Special Interest.—With the exception of the large plants of the Sanitary District of Chicago, which include many different types of units, the plants that may have special interest are those at Princeton and Springfield. The Princeton plant is described in the paper by Mr. Roe in this issue (p. 615). This plant includes separate settling tanks with clarifier mechanism, an old septic tank remodeled for separate sludge digestion, mechanical Simplex aerator units, a secondary settling tank with sludge mechanism, and a sludge-drying bed formed from an old trickling filter. Several 24-hour test runs have been conducted on this plant and analytical and power cost data are available.

The Springfield plant comprises grit chambers, separate settling and sludge digestion tanks with gas collection and utilization, aerators using Filtros plates, secondary settling tanks with sludge mechanism and both

covered and uncovered sludge beds. The best arranged and equipped laboratory for any sewage-treatment plant in the state outside Chicago is an adjunct of the Springfield plant. A very interesting feature of this plant is the primary settling tanks equipped with Dorr and Link-Belt mechanisms operating in parallel. With these tanks receiving the same quality of sewage at the same rates of flow there will eventually be available reliable information on their comparative efficiencies and operation costs.

The Future of Sewage Treatment in Illinois.—It has previously been noted that there are 22 sanitary districts in Illinois organized under one law, the Chicago and North Shore Sanitary Districts organized under separate laws, and all districts organized for the treatment and sanitary disposal of sewage. Also as previously stated these districts comprise nearly two-thirds of the entire population of the state. A definite sewage-treatment program is actively under way in the Chicago area and in the other sanitary districts rapid progress has been made during the last three years. It is certain that still more rapid progress will be made on stream sanitation and conservation because of these districts in the next few years.

For those cities not included in sanitary districts, which comprise a small percentage of the population of the state even though they are large in numbers, there will also be undoubtedly a marked increase in sewage-treatment activities because of the increasingly noticeable desire and demand for cleaner streams, and the awakening civic consciousness with regard to this question of disposal of municipal wastes.

Sanitary Water Board.—The increasing demand for cleaner streams is reflected in a law enacted by the recent Illinois legislature effective July 1, 1929, providing for a Sanitary Water Board to have definite control over stream sanitation and conservation. This law in brief provides for a board made up of the directors of four departments, a fifth member appointed by the Governor to represent industry, and the chief sanitary engineer of the State Department of Health to serve as technical secretary. The board is given definite powers relative to both new and existing sewerage works. Also provision is made for investigations of sewage and industrial wastes treatment, the condition of streams, and the establishment of standards of purity for streams. It may be hoped and expected that the coöperation of such a board with the municipalities will bring about the installation of more sewage-treatment works and better and more intelligent operation of existing works without having to resort to the issuance of orders or court action, except in rare cases.

A statistical study of sewage treatment in Illinois at the end of 1930 will, therefore, be of interest as compared with the status at the present time.

Status of Sewage Treatment in Indiana

BY LEWIS S. FINCH[1]

Until recent years Indiana has been largely an agricultural state, but industrial development is increasing so rapidly that at present Indiana is fast becoming an industrial state. Under such circumstances, it is but natural that the problem of properly disposing of sewage and industrial wastes should be of the utmost importance. In fact, there exist at present very objectionable conditions in practically all sections of the state, whether they be agricultural or industrial districts.

In the agricultural districts, in addition to domestic sewage, wastes from canneries, milk plants and strawboard mills are principally responsible for pollution of streams. In the industrial districts, wastes from steel mills, oil refineries and gas works add to the problems of disposal of domestic sewage.

Domestic Sewage

At the present time there are relatively few municipal treatment works in existence in Indiana. The various types of treatment plants in operation are listed in the following tabulation:

Type of Plant	Now in Operation	To Be under Construction This Season
Septic tanks	10	
Septic tanks and contact bed	3	
Septic tanks and sprinkling filter	2	
Imhoff tanks	8	1
Imhoff tanks and contact bed	1	
Imhoff tanks and sprinkling filters	6	2
Sedimentation, separate sludge digestion and sprinkling filters	2	
Sedimentation, separate sludge digestion, sprinkling filters and chlorination	1	
Sedimentation, separate sludge digestion, sprinkling filters and gas collection utilization		1
Activated sludge	1	
Total	34	4

Of the four plants which will be under construction during this construction season, the one at Gary will be the largest, the estimated cost including interceptors being $2,500,000.

There are several other plants which would be under construction this season, but for the fact that this is the year in which municipal elections will be held and the local officials in many places do not care to assume the responsibility for large expenditures immediately before election.

It is expected that during 1930 cities and towns with an aggregate population of at least 450,000 people will have works under construction. This

[1] *Chief Engineer, Indiana State Board of Health.*

amounts to slightly over 10 per cent of the entire population of the State. The larger cities in this group are Fort Wayne, South Bend, East Chicago, Muncie, Anderson, Kokomo and New Castle. It is also possible that Hammond, Whiting and Michigan City may be included in the above group although these cities were not included in the 450,000 people previously mentioned.

While there are now 34 municipal sewage treatment plants in the state there are only two which are being operated with effective laboratory control. These are the plants at Indianapolis and Frankfort. Several others are being carefully operated without such control, but the majority are running without any supervision whatever. In fact, in several instances, engineers of the State Board of Health, during the past year, have found that plants were being bypassed completely or being operated in such a manner that no treatment whatever was being accomplished.

In one case it was found that sewage was flowing into an Imhoff tank in the normal manner but was being discharged through the sludge blow-off pipe. At another plant an inspection was made in response to a complaint that raw sewage was being discharged to the stream. It was found that the plant was being completely bypassed and none of the local authorities realized the state of affairs. From the condition of the tank it appeared that no sewage had been run into it for several years.

It is unfortunate that such conditions should exist but so long as the local officials do not realize the importance of properly operating the plants little improvement can be expected.

Unless adequate funds are provided by municipalities for the operation and maintenance of sewage treatment works, the plants cannot be effectively operated nor can properly trained operators be secured. In an attempt to make it possible to raise such funds, a bill providing for the collection of sewer service charges was introduced in the 1929 Legislature. Unfortunately, however, the Legislature adjourned without having taken final action on it.

If the State Board of Health had sufficient engineering personnel to enable it to devote the necessary attention to the operation of existing plants, better operating results could be secured. Unfortunately, however, in Indiana the engineering staff is so small that very little time can be devoted to this problem.

At present, monthly reports of operation of sewage plants are required by a regulation of the State Board of Health, but since it is impossible to check up these reports by personal inspections, part of their value is lost.

Industrial Wastes

The industrial waste causing the most complaint and affecting the largest number of people in Indiana is that from the by-product coke plants in

the Calumet District in Northern Indiana. There are about 300,000 people in this district whose drinking water is made almost undrinkable by the discharge of phenol-bearing wastes from the coke plants of the Illinois Steel Company at Gary and the Inland Steel Company and the Youngstown Sheet & Tube Company at East Chicago. These companies discharge phenolic wastes directly or indirectly into the southern end of Lake Michigan which is the source of the drinking water supply of Gary, East Chicago, Whiting and Hammond in Indiana and the City of Chicago, in Illinois.

Fortunately the industries responsible for these wastes have, with one exception, attacked the problem and are spending huge sums to prevent the continued discharge of phenol into the lake.

At present the Illinois Steel Company has under construction works which will make it possible to dispose of this waste by quenching coke with it. When completed, this plant will have cost in excess of $900,000.

The Inland Steel Company will soon let contracts for the construction of a Koppers phenol recovery plant which will cost over $600,000.

Fort Wayne has a by-product coke plant which discharges its wastes into the Maumee River. This stream, after receiving this waste, flows into Ohio and is responsible for chloro-phenolic tastes in the water supply at Defiance, Ohio.

There are two by-product coke plants at Indianapolis, one of which discharges its wastes into Fall Creek. The water from this stream is not normally used for drinking water, but it is considered as an emergency supply. It could not be used, however, without causing very offensive tastes.

Phenolic wastes are discharged at Terre Haute into the Wabash River and occasionally affect the water supply at Vincennes.

At several points in the state "pickling liquor" is responsible for objectionable stream conditions. The large oil refineries in the Calumet District cause tastes in the public water supply at Whiting.

Canneries and strawboard mills are the chief source of objectionable wastes in the agricultural districts, although creamery wastes also contribute their share to the general problem of stream pollution.

The problem of improving the Indiana streams by preventing undue pollution by these wastes is being handled by the State Board of Health through coöperation with industry.

Stream Improvement

Indiana statutes provide sufficient authority to permit the State Board of Health to accomplish whatever may be necessary to improve Indiana streams where such improvement is necessary. As indicated above, this is being accomplished by coöperation with municipalities and industry

rather than by force, but should force be necessary, the statutes provide adequate authority.

Increased activity in stream improvement work on the part of the State Board of Health, became possible during 1928 and 1929 because of funds contributed by the International Health Board of the Rockefeller Foundation. It is possible that these funds may be withdrawn on October 1, 1929, but it is hoped that money will be made available by the Legislature to enable the work to continue.

In any event, sufficient data have already been secured to make it possible to accomplish the improvement of many of the worst conditions.

Disposal of Phenol Wastes.—Three papers on disposal of phenol wastes have appeared in the *American Journal of Public Health* within the past year.

F. W. Sperr, Jr., Director of Research, The Koppers Company, Pittsburgh, discusses methods of treatment of these wastes from the standpoint of the by-products coke manufacturer, in an article on page 901 of the August, 1929, issue. He states that at present the most promising processes are based on the employment of physical and biological means. Those which have reached large-scale operation he lists as follows:

1. Disposal by complete evaporation.
2. Preheating liquor entering ammonia still.
3. Extraction of phenols with solvents.
4. Removal of phenols with solid adsorbents.
5. Biological treatment.

Researches on the biological oxidation of phenol wastes in sewage are described by Dr. F. W. Mohlman, Chief Chemist of the Sanitary District of Chicago, on page 145 of the February, 1929, issue. Each part per million of phenol increased the 5-day B. O. D. of the sewage by 1.7 p. p. m. Experiments with sand filters indicated that they would tolerate up to 25 to 35 p. p. m. of phenol in the applied sewage without serious interference with biological oxidation. Activated sludge experiments at Milwaukee and in Waldenburg, Germany, showed tolerance up to 30 or 40 p. p. m. Increase of temperature accelerated the rate of oxidation in river waters.

Conditions under which results were obtained in phenolic wastes disposal in the Ohio River Basin are discussed in the July, 1929, issue on page 758 in an article by F. H. Waring, Chief Engineer, State Department of Health, Columbus, Ohio. Experiences with phenolic wastes in this area and the efforts of industries to eliminate them are given from both economic and popular standpoints. Methods for the extraction of phenol including the Heffner-Tiddy Process are explained in detail.

Sewage Treatment in Missouri

BY W. SCOTT JOHNSON[1]

This paper is a compilation of the available data on sewage treatment in Missouri and purposes to treat the present status of the subject for the state as a whole. The information contained herein has been collected over a period of several years, during which annual inspections and many special investigations have been made of sewage treatment plants in the state. In making these inspections considerable additional information has been secured relative to the use and availability of public sewer systems and to the solutions of various difficulties in operation.

Consideration of sewage treatment in Missouri must necessarily be prefaced with a brief discussion of the distribution of sewered population relative to the large rivers in the state. The Missouri River, with a low mean annual discharge of 36,500 cu. ft. per sec. at St. Joseph, forms the west border of the state for approximately 180 miles, and turning at Kansas City flows approximately 400 miles easterly across the width of the state to the Mississippi River. The latter river, with a minimum flow of 42,000 cu. ft. per sec. at St. Louis, forms practically the entire eastern boundary of the state, a distance of approximately 500 miles. Along this total of approximately 1000 miles of river are located 19 of the 126 cities in Missouri which have sewer systems. These 19 cities have a total population of 1,260,165, or 77 per cent of the sewered population of the state.[2] None of the sewage from these 19 cities is treated.

For the present, disposal of this large volume of sewage without treatment into the Missouri and Mississippi Rivers is considered satisfactory. The importance of these rivers as regards sewage disposal is even more significant when it is realized that if every incorporated city in the state had a sewer system, only 22 per cent of the sewered population would not have these two rivers available for disposal of sewage.

The remaining large rivers in the state, including the Osage, White, Gasconade and Grand, receive sewage directly from only about one per cent of the sewered population of the state. The dilution is sufficient to dispose of the sewage satisfactorily. Sewage from the remaining sewered population, representing 22 per cent of the total of the state, requires treatment. Consequently the subject matter of this paper deals with a relatively small per cent of the population of the state which must necessarily resort to sewage treatment because of its location away from the large rivers.

As a result of routine surveys made by engineers of the State Board of Health over a period of several years considerable information has been secured relative to sewerage, and particularly sewage treatment works in

[1] *Chief Public Health Engineer, State Board of Health of Missouri.*

[2] *All populations taken from 1920 census.*

Missouri. This information has been compiled as completely as possible in tabular form.

Table I contains data regarding the sewerage works existing in cities divided according to three population groups. This data emphasizes the fact that the lack of municipal sewers is practically confined to cities of less than 2500 population and is especially pronounced in cities of less than 1000 population. Of the 63 cities of 2500 population and over, only 6, not located on the Missouri or Mississippi Rivers, are without some type of sewage treatment.

Table I shows the rather discouraging fact that 581 of the 707 cities in Missouri are without sewers, but these 581 cities contain only 10.1 per cent of the urban population, as shown in Table II. This table also indicates that more than 76 per cent of the urban population is supplied with sewer systems but without sewage treatment. This is due to the fact that the largest cities, containing 70 per cent of the total population within incorporated cities, are located on the Missouri and Mississippi Rivers. Likewise, this condition accounts for the small percentage, 13.3, of urban population which has sewage treatment. A total of 90 per cent of the population within incorporated cities has sewers available. It is of interest to note that 46.8 per cent of the state population is rural, therefore, only 48 per cent of the total state population has sewers available.

TABLE I

SEWERAGE WORKS DATA FOR MISSOURI CITIES BY POPULATION GROUPS

Number of Cities	Under 1000 Population	1000–2500 Population	Over 2500 Population
Without sewers	513	64*	4**
Sewers only	7	16	19
Combined sewers		1	14
Sewage treatment	8	35	26
Total	528	116	63

* One of these 64 cities constructing sewers.

** One of these 4 cities is building sewers and one city is voting on a bond issue for sewer construction.

TABLE II

SEWERAGE WORKS DATA ON POPULATION BASIS

Data	Number of Cities	Total Population	Per Cent of Total City Population
Without sewers	581	183,154	10.1
Sewers only	57	1,389,461	76.6
Sewage treatment	69	242,139	13.3
Total	707	1,814,754	100.0

Table III indicates the type of plant installed in the 69 cities with sewage treatment. This table lists 84 treatment plants, since several cities have two or more plants. Primary treatment only is employed at 61 plants,

and Imhoff tanks are slightly in the lead over septic tanks with regard to number and population served. All of the septic tanks were constructed more than seven years ago, and no additional municipal treatment works of this type have been constructed since the engineering division of the State Board of Health came into existence. There are 23 plants which include both primary and secondary treatment. Sprinkling filters have been employed for secondary treatment almost to the exclusion of all other types. There is being constructed at the present time the first activated sludge plant for the treatment of municipal sewage. Chlorination in conjunction with biological processes has secured a start in Missouri. Two plants are using this chemical for odor control, and two as a final adjunct to the present treatment, in order to secure stability in a small stream until greater dilution is available.

TABLE III

DATA ON TYPES OF SEWAGE TREATMENT WORKS

	Primary Treatment Only			Primary and Secondary Treatment				Chlorine in Addition to Other Treatment	
Type of Treatment	Septic tanks	Imhoff Tanks	Separate Sludge Digestion	Sprinkling Filters	Sand Filters	Contact Filters	Total*	Prechlorination	Final Chlorination
No. of plants	28	32	2	18	1	4	84	3	1
Population	50,719	52,818	17,053	105,287	3,248	14,409	242,450	13,691	3,760

* One city has chlorination only.

TABLE IV

DATA ON OPERATION OF SEWAGE TREATMENT WORKS

		Satisfactory		Not Satisfactory		Causes of Unsatisfactory Operation			
Operation		No.	Population	No.	Population	Insufficient Treatment	Design	Operation	Industrial Wastes
Dilution		41	1,337,998	16	49,968	16			
Primary treatment only	Septic tanks	13	19,375	15	31,344	6	7		2
	Imhoff tanks	22	39,131	10	13,687	3	3	3	1
	Separate digestion			2	17,053	2			
Primary and secondary treatment	Sprinkling filter	14	100,450	3	4,837		1	2	
	Sand filter	1	3,248						
	Contact filter			4	14,509		1	3	
Total		91	1,500,202	50	131,398	27	12	8	3

Table IV attempts to indicate, in tabular form, operation data regarding sewage treatment and disposal in Missouri, and the causes of unsatisfactory operation. It is noteworthy that in 35.5 per cent of the cases sewage treatment or disposal is not satisfactory. However, only 132,616 people, or 8.1 per cent of the population served by sewers, is affected by these condi-

tions. Insufficient dilution is most frequently the cause of trouble; poor design is second as a cause of unsatisfactory results; operation third, and industrial wastes fourth.

The problem of securing initial or additional treatment for municipal sewage is largely a matter of finances and the development of a consciousness of responsibility regarding rights of others.

In Missouri a city council can order the construction of a sewage treatment plant to be paid for by tax bills against the property benefited. Also, by a two-thirds majority vote a city may bond itself to the extent of 5 per cent of the next to the last completed valuation of property for the purpose of constructing sewer systems or sewage treatment works. The latter is the usual method employed in financing the construction of sewage treatment works. In developing a civic consciousness relative to sewage treatment, the State Board of Health has in many instances secured the desired results through surveys, reports and talks at mass meetings. In certain cases a court suit, or the threat of one, has produced a wholesome respect for the rights of others, and the construction of treatment works was begun without further delay.

Since the approval of plans for sewerage works by the State Board of Health has been required, the design of these works has improved, especially with regard to capacities of various units. In many cases, due to lack of funds, the original construction does not include as complete treatment as eventually will be required. The present tendency, when funds are limited, is to finance by bond issue, at least, a satisfactory primary treatment plant with trunk line sewers and to extend the sewer lines by the district tax bill method as a demand is created. By the time additional sewage treatment is necessary some appreciation of the advantages of sanitary sewers has developed, there is less opposition to voting bonds for this purpose, and the existing plant is of satisfactory design for inclusion in the completed works.

Poor operation is the result of causes similar to those affecting the construction of sewage treatment plants, namely, lack of funds and indifference. The old idea that sewage treatment works are automatic magic machines which need no attention has not been entirely dispelled. Also, political interference with operators who have become trained is an obstacle to good operation. The cost of technically trained personnel for supervision of the smaller plants is so greatly out of proportion to populations served that such operation can hardly be expected in the near future. It may be that a sewer rental law, similar to the one in Ohio and Michigan, will constitute a less painful and more efficacious method of extracting money for the maintenance of sewers and treatment plants. However, in Missouri there seems to be no difficulty in securing funds by the usual taxation method, provided the need and necessity is sufficiently impressed

upon city officials and the public. It is doubtful if it would be any less difficult, or less objectionable to the average city councilman, to secure money for maintaining sewerage works by putting a rental law into effect than by raising the tax levy. A threatened law suit, demands of certain organizations, regular inspections and special investigations by the State Board of Health, with reports and recommendations, are gradually developing a better understanding of the need for satisfactory operation.

Industrial wastes are not a particularly serious problem in relation to the operation of sewage treatment plants in Missouri. In the few cases where this is a factor the wastes are from milk or milk product plants and the recommended remedy in most cases has been to require preliminary treatment of these wastes. At the present time one municipal plant is being built for the purpose of treating raw milk wastes in conjunction with the city sewage.

In general, the present trend of sewage treatment in Missouri has many encouraging aspects. Fifty-one of the existing 84 sewage treatment plants have been built since 1922. The growing interest in outdoor life, involving recreational use of our streams and rivers, has served to interest many in the need for adequate sewage treatment. The rights of riparian land owners is becoming better established and there is less hesitancy in resorting to the courts for relief. The efforts of the State Board of Health, particularly the annual inspection, special studies and instruction in sewage treatment, and the effect of the annual meetings of the Missouri Water and Sewerage Conference are awakening interest in, and improving the technique of the operation of sewage treatment plants.

The progress secured should not disguise the fact that many cities with water supplies are still without sewerage works. In several instances streams are being badly polluted through lack of sewage treatment, and the operation of many plants is far from satisfactory. However, it appears that an increasing number of citizens and city officials are acquiring an understanding and responsibility with regard to sewage treatment which predicts greater improvements in the future.

Sewage Treatment at Madison, Wisconsin[1]

BY JAMES MACKIN[2]

Madison, Wisconsin, was a pioneer among American cities in the treatment of its domestic sewage. The first treatment plant, which was a chemical precipitation plant, was put in operation more than 30 years ago. This plant failed in spite of the fact that it was enthusiastically recommended and a definite guarantee was made that it would operate satisfactorily. It failed not only in the results of treatment, which produced an unsatisfactory effluent, but also the cost of operation was twice the maximum guaranteed cost. This plant was operated for about a year and a half from June, 1899, to January, 1901. The city, of course, reclaimed all its investment through court procedure.

A word concerning the reasons for such early treatment of domestic sewage might be interesting. Madison lies between Lakes Mendota and Monona, which are very beautiful and a source of pleasure not only to the residents but also to the many tourists. From an aesthetic as well as a commercial standpoint, it was desirable to prevent the lakes from being grossly polluted, especially since lawsuits were being instituted against the city for maintaining a nuisance.

After the failure of the chemical precipitation plant, a septic-tank cinder trickling-filter process of treatment was employed. This plant, which was designed by the city engineer at that time, Mr. Turneaure, who is now Dean of the College of Engineering at the University of Wisconsin, was in operation from 1901 to 1914. The details of this plant are found in general in Mr. Parker's paper on "The New Nine-Springs Disposal Works at Madison, Wisconsin" (Twentieth Annual Report, Engineering Society of Wisconsin, pp. 148–164, July, 1928) and in particular in Mr. Icke's review of sewage treatment at Madison in "The Wisconsin Engineer" of 1905. (Copies of Mr. Parker's paper are available to any one desiring them.)

The septic-tank trickling-filter plant was abandoned in 1914 when it was receiving 3,500,000 gallons per day, which was more than double its capacity of 1,500,000 gallons per day. At this time the site of the plant was very undesirable, since the city had grown greatly and dwellings partially surrounded the property.

In 1912 it was deemed advisable to start construction on a new treatment plant, preferably outside the city limits. This plant was designed by John W. Alvord to treat all sewage until the year 1930. In Mr. Parker's paper, previously mentioned, the engineering features are considered in

[1] *Read at Second Annual Meeting, Central States Sewage Works Association, Indianapolis, Ind., June 20, 1929.*

[2] *Superintendent, Sewage Treatment Works, Madison, Wisconsin.*

detail. This so-called Burke Plant, of the separate digestion type, was located two miles north of the existing plant. The new plant was put in partial operation in 1914, when tank treatment only was afforded. Early in 1916 the trickling filters were completed and put in operation. This plant has a capacity of 5 million gallons per day and is still in operation.

The New Nine-Springs Treatment Plant

In 1920 the capacity of the Burke Plant was reached in spite of the previous careful calculations which indicated that a flow of 5 million gallons

Trickling Filters, Nine-Springs Treatment Works in Sub-zero Weather, February, 1929.

per day would not be reached until 1930. Negotiations for the construction of further treatment units were then begun, but it was decided to build the new plant of Imhoff tanks followed by trickling filters and secondary sedimentation tanks, with separate units for grit and grease extraction and chlorination.

The sewage from the western part of the city of Madison, is pumped three and one-half miles from the southwest city limits to the new Nine-Springs Treatment Plant. The capacity of this plant, which was officially put in operation June 28, 1928, is five million gallons per day. The present construction is on one side of the center line of a ten-million-gallon

plant and other provisions are made for extensions. Sufficient head is allowed between tanks and filters to provide for aeration if desired later.

In 1924 a 30-inch cast iron force main was built from the west side pumping station $3^1/_2$ miles to the new site and connections made so that the west side station will pump from the city to the new plant, while the east side pumping station will continue to serve the Burke Plant.

At Nine-Springs the sewage first enters a twin grit chamber and grease extractor 25 ft. by 13 ft. in plan, and 14 ft. deep. Thence it flows to a battery of six rectangular Imhoff tanks, each 30 ft. × 64 ft. in plan, and 31 ft. deep. The detention period is $2^1/_2$ hours at capacity rate of flow. Each Imhoff tank has two flowing-through hoppers, designed for reversible flow.

The clarified sewage passes to twin dosing tanks which discharge at 15-minute intervals through 572 Taylor nozzles upon two one-acre trickling filters which contain ten feet of crushed limestone on a Fitchburg-type floor. Each bed has a central pipe gallery (containing also the effluent channels) and flushing galleries at the upper ends of the floor drains. Special provisions are made for rodding and flushing the lateral pipes.

The filter effluent passes to two Dorr clarifiers 50 ft. square, 9 ft. $2^1/_2$ in. deep, and thence through a reinforced-concrete-box outfall sewer to the drainage ditch, which empties into the Yahara River between Lakes Monona and Waubesa. Provision is made for chlorination between the filters and the Dorr clarifiers. At present experiments on the chlorination of the raw sewage are being made in an attempt to eliminate odors.

In July and August, 1928, considerable odors were encountered at the new plant. This condition was due to the septicity of the sewage as it arrived at the treatment plant. The 30-in. pipe $3^1/_2$ miles long has such a very large capacity that the sewage leaving the pumping station at the minimum rate of flow required 10 hours to reach the treatment works. This sewage was consequently very septic when it reached the plant. In order to avoid this undesirable situation, lake water was admitted into the pumping station and used to dilute the sewage. The lake water was admitted at the rate of $1^1/_2$ million gallons per day during minimum flow, which additional flow almost doubled the velocity in the pipe, as well as acting to dilute the sewage, thereby delivering the sewage to the plant in a much less septic condition. By this means the odors were practically eliminated. This was done before the necessary chlorine facilities were available. The present experiments with chlorine will bring out the facts as to which method would be most desirable from the standpoints of efficiency and expense—chlorination or dilution.

Digested sludge from this plant is dried on an acre of sludge beds, which drain to the clarifiers.

A complete water supply is provided on the site consisting of a two-room pump house of reinforced concrete and brick, 16 ft. by 32 ft. in plan,

equipped with a Layne 15-in., 8-stage, deep-well pump set 198 feet below the operating floor in a well 828 feet deep.

Pearse, Greeley & Hansen, of Chicago, were the consulting engineers in the design of the new treatment plant.

Interesting innovations in sewage treatment are made possible by details of design which are outlined in Mr. Parker's paper, previously mentioned. The interesting possibilities in treatment afforded by the special construction include: (1) The removal of the top sludge in the gas vents. This sludge can be collected in a sludge well and either pumped to sand-drying beds or to a gas vent in any other tank. (2) The removal of bottom sludge is, of course, standard; but in Madison this bottom sludge can be circulated through the same tank by pumping it into a gas vent; or it can be introduced into a gas vent of any other tank; or it can be pumped to the drying beds.

The advantages of such procedures are: (*a*) if one sludge chamber is overloaded, relief may be temporarily obtained by putting the surplus sludge into another chamber; (*b*) if digestion in any of the sludge compartments is not efficient, sludge from another chamber can be introduced to promote activity in the poorly working sludge chamber.

The sludge from the secondary sedimentation tanks can either be introduced into the raw sewage or pumped into a gas vent of any tank.

The skimmings from the flowing-through chambers can be collected by a T-shaped wooden float, and the accumulated scum can be run into the effluent channel not in use. The reversible-flow feature of the plant always leaves one effluent channel unused. From the effluent channel the skimmings flow to the sludge well, from which they can be pumped to the drying beds or into a gas vent of any tank.

Bailey flow meters in the administration building indicate the flow of sewage in each flowing-through chamber, and a special inlet valve and Venturi meter are provided for each tank so that the flow can be equalized.

The administration building is a 3-story structure 30 ft. × 30 ft. in plan. It houses the offices, a fully equipped laboratory, sludge pumps and some of the meters.

The Effect of Treatment

The effect of the grit and grease-extraction chambers is self-explanatory. The fact that some organic matter collects in this chamber in spite of the rapid rate of flow is common experience in sewage practice.

The Imhoff tanks have worked quite successfully in the removal of suspended matter and under ordinary circumstances a tank effluent is produced which contains between 25 and 40 parts per million of suspended solids. The percentage removal is of very limited value in judging the efficient operation of sedimentation tanks because the percentage removal is affected primarily by the content of suspended matter of the influent. The signifi-

cant item is the suspended matter in the tank effluent, which is indicative of the load on the filter beds. The reduction of biochemical oxygen demand due to the removal of suspended matter by the Imhoff tanks is from 85 to 175 p. p. m. and is more or less directly proportional to the reduction of suspended matter. The B. O. D. of the tank effluent averages 80 to 90 parts per million.

The trickling filters have performed their functions in a most efficient manner. The filter effluent has an average B. O. D. of only 15 to 20 p. p. m. which is a reduction of 65 to 75 p. p. m. from the B. O. D. of the tank effluent. The dissolved oxygen of the final effluent has never been below 8.0 and at times during the winter months it has been as high as 12 parts per million. This high dissolved oxygen content is an unusual occurrence in Madison's experience, and it may be due to the greater depth of the filter beds (10 feet). Results at Burke Plant showed a lower dissolved oxygen content during the winter months, which was attributed to the fact that the growth and effect of the bacteria in the 6-foot filter beds were probably greatly inhibited at the low winter temperatures.

The ammonia of the tank effluent is converted almost entirely to nitrites and nitrates by bacteriological action in the filter beds, consequently the amount of nitrites and nitrates produced is dependent upon the ammonia concentration in the tank effluent. In general, the filter effluent averages 1.0 p. p. m. nitrite nitrogen and 10 p. p. m. nitrate nitrogen.

A typical analysis showing the effects of treatment at the new treatment plant follows:

CHEMICAL ANALYSIS OF MADISON SEWAGE

Nine-Springs Treatment Plant

All Samples Are Composites of 1 Liter Hourly from 7 a.m.–4 p.m.

Date: April 15, 1929

Results in parts per million

Sample	Nitrogen			Oxygen		Solid Matter		
	NH_3–N Ammonia	Org. N	NO_3–N Nitrate	Consumed	5-Day B. O. D.	Total	Volatile	Suspended
Grit chamber effluent	12.0	32.0	Trace	90	215	850	128	158
Tank effluent	13.0	26.4	Trace	46	63	740	37	45
Filter effluent	0.96	15.0	12.0	21	14	740	24	42
Dorr clarifier effluent	0.84	15.0	12.0	16	9	700	14	20

The Dorr clarifiers removed the stone dust which was washed off the filter stone when the plant was put in operation, but there was no other function for them to perform during the first 10 months of operation, since there was no unloading. These clarifiers were of considerable value during the first unloading period which began 2 months ago (April, 1929) and is nearly completed. During unloading the filter effluents contained from 100 to as high as 400 p. p. m. of suspended matter, of which the Dorr clarifiers removed from 40–65 per cent and produced an effluent which con-

tained only 50–150 parts per million. This removal of suspended matter during unloading periods is practically the only function of the Dorr clarifiers, and the recent experience has shown that it is efficient in performing this function.

Before the Imhoff tanks were put in operation, they were filled with artesian well water and then each digestion compartment was seeded with 10,000 gallons of well-digested sludge from the Burke Plant. The analysis of this sludge used to inoculate the new tanks may be of interest to many sewage operators. The analysis of a composite sample follows:

	Per Cent
Specific gravity	1.024
Moisture	91.0
Solid matter	9.0
Loss on ignition (volatile matter)	54.4
Fixed matter (ash)	45.6
Total nitrogen	0.318

Digestion in the new tanks has proceeded normally since the beginning of operation. The sludge has dried exceptionally well on the sand-drying beds, and the top sludge was observed to dry fully as well as the bottom sludge.

The following data offer a comparison of top and bottom sludge at the New Treatment Plant. The results were obtained on hand samples which were collected May 10, 1929:

	Top Sludge, Per Cent	Bottom Sludge, Per Cent
Specific gravity	1.000	1.001
pH	7.0–7.1	7.0
Moisture	94.6	95.34
Solid matter	5.4	4.66
Loss on ignition (volatile matter)	73.78	58.05
Fixed matter (ash)	26.22	41.95
Total nitrogen	0.163	0.163

The sludge as removed from the sand-drying beds at both plants is sold in Madison as fertilizer for $1.00 a cubic yard. The purchasers must call for and remove the sludge. In 1928 the revenue from this source approximated $800.00. The average analysis of this sludge indicates that it is a very valuable fertilizer and it also acts as an excellent soil conditioner. The analysis of the sludge first removed from the drying beds at the Nine-Springs Treatment plant follows:

Moisture	52%—a low value; usually 70% and sometimes as high as 80%
Total nitrogen	1.87% on wet basis 4.00% on dry basis
Total phosphorus (P_2O_5)	3.05% on dry basis
Potassium (K_2O)	0.36% on dry basis

Gas Collection from Imhoff Tanks[1]

BY WELLINGTON DONALDSON[2]

That the normal digestion of the organic solids from sewage under anaerobic conditions is accompanied by the production of considerable amount of combustible gas has long been known. It is only in recent years however, that serious attention has been given to the capture and utilization of this by-product of sewage works operation. The concentration of effort both here and abroad in recent years on serious research study of sewage digestion problems has given a new impetus to the collection of gas with the result that works have been constructed in various parts of the world in which are embodied the feature of gas collection and its utilization by adapting existent two-story digestion tanks, by the design of new two-story digestion tanks, or by separate sludge digestion. It is not within the scope of this paper to discuss the merits and demerits of the two principal types of sludge digestion devices but it will deal particularly with the experiences with two-story tanks in this country.

Historical

The first attempt in this country to utilize in a practical way the gases from Imhoff tanks, so far as the writer is aware, was at the Peachtree plant in Atlanta, where C. C. Hommon in 1915 (*Engineering Record*, **73,** 182 (Feb. 5, 1916)) placed galvanized covers over three of the thirty gas vents of his Imhoff tanks and successfully utilized this gas for fuel in the laboratory and dwelling. The idea was not extended to the remaining vents and the installation later fell into disuse.

At Austin, Texas, concrete covers were placed over the Imhoff tank and pump sump in 1921–22 for the capture and combustion of malodorous gases, which had involved the city in litigation. A small pump withdraws the tank gases at lower than atmospheric pressure and discharges them to an outside brick furnace. Incidentally a portion of the waste gases is utilized to heat the building during cold weather. The main features of the installation were described by Leonard (*Engineering News-Record*, **88,** 565 (April 6, 1922)).

The grit chamber, gas vents and flow channels of the Imhoff installation at Decatur, Illinois, were partially covered in 1925, and completely covered in 1926, specifically for the abatement of hydrogen sulfide odor. The Decatur experience has been fully reported by Hatfield (*Public Works*, **58,** 204 (1927)) and by Hatfield, Symons and Mills (*Ind. Eng. Chem.*, **20,** 174 (1928)).

[1] *Presented at the Third Annual Conference, Pennsylvania Sewage Works Association, Harrisburg, Pa., July 16, 1929.*

[2] *With Fuller and McClintock, Engineers, New York City.*

The publication of the Essen experiences with gas collection by Dr. Imhoff (*Engineering News-Record*, **91,** 512 (Sept. 27, 1923)) redirected attention to the possibilities of recovering useful products from sewage treatment. His visit to this country in 1926, and publication of subsequent Essen experiences (*Engineering News-Record*, **99,** 790 (Nov. 17, 1927)) did much to stimulate interest in the subject. Meanwhile, the conspicuously valuable research work on sludge digestion in this country by Rudolfs at the New Jersey Experiment Station, by Baity and Fair at Harvard, and by others was being translated into engineering practice.

At the Calumet works of the Sanitary District of Chicago, one of the thirty Imhoff tanks was equipped for gas collection and has been in service since February, 1926, for experimental study under close laboratory supervision. The results of recent operation are given by Zack and Edwards (THIS JOURNAL, **1,** 160 (1929)) together with a concise review of the practice of gas collection from various types of tanks.

New Castle Installation

The Imhoff tanks at New Castle, Pennsylvania, completed in October, 1926, which will be particularly referred to in this paper, are probably the first of the new crop of full plant-scale Imhoff tanks in this country designed with integral structures for gas collection, though others have been approved for building or are under construction.

The New Castle installation comprises bar screens followed by Imhoff tanks. The six Imhoff units are each approximately 25 ft. wide by 75 ft. in length and 30 ft. deep. The tanks are provided with the usual channels for reversing flow, which is now done on a weekly schedule. Each tank has a double line of slots trapped by a triangular beam. For the capture of gas, the usual gas vent spaces are closed by submerged sloping concrete roofs integral with the tank structure, the gas slopes terminating in 6 gas shafts per tank, each 28 inches square. This means 2 gas shafts to each of the side slopes and 2 to the double center slope, located at points about one-fourth the length of the tank from the end. The total number of gas shafts in the installation is thus 36. The upper end of the gas shafts is restricted to a 16-inch square opening to support the gas screen and collection bell. As originally installed there was a wooden frame or box 12 inches deep for holding the screen proper, consisting of a loosely jointed tongue-and-groove plate, after the Imhoff design. Upon the frame was a pyramidal cast iron bell 24 inches square in base and 24 inches high. The screens were set so as to be completely submerged and the flow line of the tank intersected the gas bell about half way up. From the top of each gas bell, $^1/_2$-inch pipe connections were made to one of the two manifold gas pipes on the tank. These manifold pipes, increasing from $1^1/_2$ inch to 2-inch diameter, join at the end of the tank, where they connect

with a 4-inch gas line leading to the meter, thence to the buildings and to the outside trap and burner.

The gas meter is a 4-inch positive displacement type supplied by the Metric Metal Works and commonly used in the natural gas field. The gas line beyond the meter is branched, one branch leading to the outside oil seal and waste burner and the other branch to the buildings. Any gas not used in the building overflows, so to speak, through the oil seal to the outside burner. The oil seal is simply a pipe loop kept partially filled with oil to give any desired gas pressure on the system. A water manometer in the building indicates the gas pressure, which is kept nominally between 3 to 5 inches of water head. The outside waste burner is a vertical piece of 2-inch pipe about 8 ft. long surmounted by a perforated metal shield or can, to prevent extinguishment of the flame by the wind.

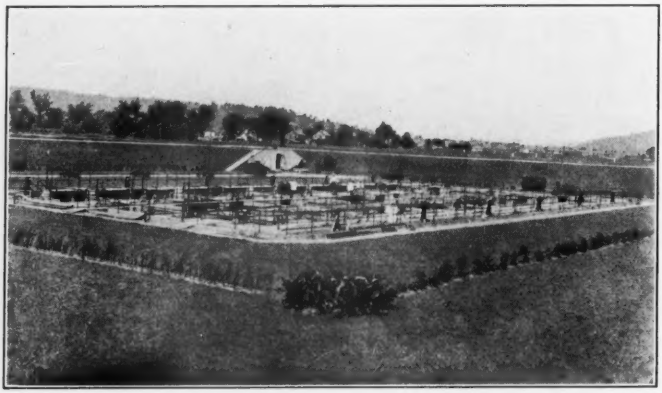

FIG. 1.—General View of Imhoff Tanks, New Castle, Pa.

For a check on quality of gas produced there is provided in the office a portable Orsat apparatus, supplied by the Fisher Scientific Company. The apparatus is suitable for complete gas analysis, including methane, but only the simple CO_2 determinations are made by the plant superintendent once a week. The results of these analyses have been found to be highly informative with regard to the progress of sludge digestion.

Unfortunately for the purpose of this paper, analyses of raw sewage are not available. The sewage is almost purely domestic, influenced markedly by both ground water and storm water accessions to the normal sewage flow. Population is nominally estimated at 50,000 persons. On account of the present polluted conditions of the stream into which the effluent flows, the expense of pumps for full-time operation was not justified

initially, consequently the present works must be bypassed at high stages of the river. Bypassing is necessary about 14 per cent of the time.

Operation of New Castle Plant

Initial operation of the New Castle Works was very much embarrassed by the acid condition of the sludge, as fully described elsewhere by the author (*Proc. N. J. Sewage Works Assn.*, **1928** and **1929**). These difficulties affected very greatly both the amount and quality of gas produced and the amount captured. Following the admission of sewage in October, 1926, the gas produced, though combustible, remained very low in quantity until corrective treatment by liming was started in the summer of 1927. On changing the reaction of the sludge, by the addition of lime, from a low minimum of pH 5.1 to a controlled range within 7.3 to 7.6, the gas

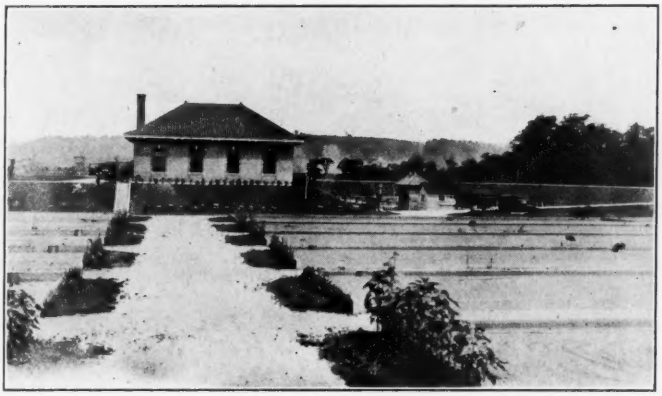

FIG. 2.—Main Building, Looking across Sludge Beds, New Castle, Pa.

production was quickly accelerated some 15-fold, accompanied by foaming. The CO_2 percentage in the transition stage reached a peak of 63 per cent and the gas was incombustible and odorous. As digestion proceeded the percentage of CO_2 gradually dropped to about 15 per cent, which is a fair average figure for New Castle.

Since the late summer of 1928, operation has been regarded as on a practically normal basis, and the figures given below may be regarded as fairly representative of this installation, though the indications now point to a considerably greater gas production this summer than in 1928.

Granted a sufficient amount of ripe sludge on hand to maintain proper biological equilibrium, the dominant factor influencing gas production in two-story tanks is the temperature. No measurements are made at

New Castle of the temperature in the digestion compartment. The air temperatures during the calendar year 1928 ranged from 3° to 98° F. During January, 1929, a minimum air temperature of −6° F. was recorded. During 1928 the temperature of the incoming sewage varied from 46° to 71° F.

Production of Gas

The total amount of gas produced has not been measured, since some of the gas bells were removed at times for cleaning or other causes. Of the 36 gas bells in the installation about 28 on an average have been in service. In speaking of gas production, therefore, a distinction must be made between the amount of gas actually passed through the meter and the estimated total based on all 36 bells being in service.

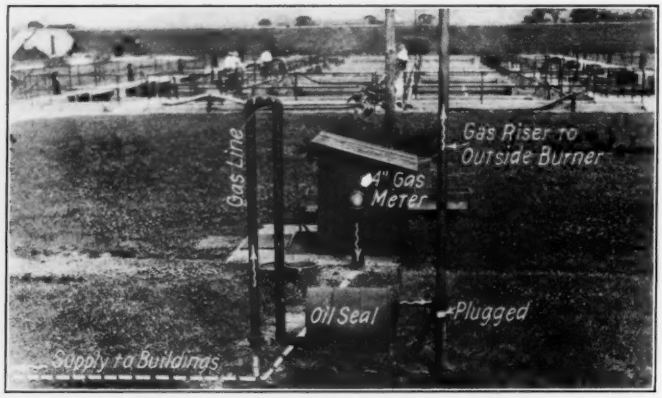

FIG. 3.—Gas Piping Arrangement, New Castle, Pa. (Revised.)

The maximum amount of gas captured and measured so far has been 34,900 cubic feet for any day or about 0.7 cu. ft. per capita, this occurring on August 29, 1928, when all gas bells were on.

With decreasing temperature during 1928 the gas production gradually fell off to a minimum of 1500 cubic feet per day on February 17, 1929. At that time, however, only 16 gas bells were in use so that the estimated total production on that day was about 3400 cubic feet or 0.07 cu. ft. per capita. Since February the gas production steadily increased until the last week in June, when the metered gas was about 24,000 cubic feet daily from 22 bells, corresponding to a total daily production of 40,000 cubic feet, or about 0.8 cu. ft. per capita. Considerable variations from day to day have been noted at New Castle, as at other plants, due to disturbances from sludge withdrawals or other causes not readily apparent.

The quality of gas has been consistently good as judged by burning quality and the CO_2 percentage. As before stated the CO_2 per cent averages about 15 per cent in the gas from the New Castle tanks. The lowest figure recorded since normal operation began was 12.0 per cent and the highest 18.5 per cent, the latter figure occurring during the June peak and coincident with the greater activity noted in the tanks.

During the winter season such gas as was necessary has been used in heating the main building and two auxiliary buildings. The surplus has been burned in the yard burner.

There have been occasional interruptions of fuel supply during the winter due to collection of frost in the small gas piping on account of the low temperatures during the night. The gas piping is exposed and is undoubtedly too small.

The principal annoyance in regard to gas collection has been the compacted accumulation of gas-lifted solids in the gas shafts and roofs, where they can be reached only with limited success by rodding, and which has required the use of a portable sludge pump. This trouble is due in part to the obstructing beams across the gas space and in part to the nature and amount of gas-lifted material. Changing the spacing of the original bar screens from 2 inches to 1 inch has improved conditions and no doubt more complete preliminary screening would further reduce the labor required to keep the tanks in condition. There have been a few occasions when foaming has caused clogging of the gas lines.

The original tongue-and-groove plate screens became clogged too readily with the floating material from the sewage solids and experiments have been made with perforated tubular screens which extend for some distance down into the gas shaft. With the elimination of the tongue-and-groove screens, the cast iron gas bells have been raised above their original position so that they are no longer partially submerged.

Discussion

Generalizations from the New Castle experiences to date are perhaps unwise. The collection of gas under American conditions from two-store tanks is feasible provided the tanks are preceded by adequate preliminary treatment to save the annoyance and labor caused by an undue amount of coarse solids. In the design of such tanks great care should be exercised to obviate obstructions in the gas collecting spaces. The gas collecting shafts and bells should be made as accessible as possible. Where the maximum gas production is needed and desired the handicaps imposed by low temperatures in northern climes are a decided limitation with two-story tanks.

Certainly at New Castle from the purely monetary standpoint the expense entailed in the capture of tank gases has not been repaid by the value

of the gas collected. There are other considerations however which may easily outweigh monetary saving. Sewage works will never be popular with the laity so long as bubbling gas vents of considerable area are exposed to the view of the casual visitor. Covering as much as practicable of sewage plants is a desirable step towards encouraging their popularity as points of civic interest or features of recreational parks.

The experiences at Austin and Decatur are very clear examples of the utility of covering tanks under certain circumstances for the prevention of odor complaints and in fending off litigation where no direct monetary return is expected.

Bio-flocculation and Gas Collection at Birmingham, England.—At the Minworth plant the settled sewage is treated by a modified activated sludge process. An aeration period of about an hour destroys offensive odors and flocculates nearly all the residual sludge-forming material. The effluent is treated on sprinkling filter beds at approximately twice the rate possible with settled sewage. An aeration unit with a capacity of 10,000,000 gal. per day is now in service and another of similar capacity is nearing completion.

Gas collected from the separate digestion tanks contains about 70 per cent methane and has a heat value of about 625 B. t. u. per 1000 cu. ft. The gas is used to operate a 150 and a 400 H. P. gas engine. The latter is the largest unit in the world using gas produced by bacterial fermentation of sewage sludge. The annual output of power will amount to $1^1/_2$ million units and will effect a saving to the board of about $10,000. *The Surveyor*, **76,** 259, Sept. 20, 1929.

Tour of British Sewage Works Managers.—A party of British sewage works managers, including representatives of most of the larger English cities, visited Belgium, Holland and Germany during the fortnight of Sept. 16–30, 1929.

Under the guidance of Dr. Ing. Prüss of the Emschergenossenschoft and Dr. H. Kessener of the Dutch Rijksinstiteuet voor Zuivering von Afvalwater, the party visited Ostend, Antwerp, Knocke, Essen, Stuttgart, Leipzig, Munich, Berlin and The Hague, where great developments have taken place in the science of trade waste and sewage purification. *The Surveyor*, **76,** 293, Sept. 27, 1929.

Activated Sludge Plants in Illinois and California with Mechanical Surface Aeration

I. Sewage Treatment Plant, Princeton, Illinois[1]

BY FRANK C. ROE[2]

The activated sludge process of sewage treatment as obtained by mechanical surface aeration has recently interested many engineers and city officials. This interest is evidenced by the number of visitors that inspect existing plants and by the inquiries that are received by the equipment manufacturers, city officials, department of health officials and by the designing engineers. An unusual amount of interest has been displayed in the Princeton, Illinois, plant, where Simplex aerators are employed, due to the fact that it was the first permanent installation within 200 miles of Chicago.

There is no new theory involved in obtaining activated sludge by mechanical surface aeration. The mechanical equipment furnishes the agitation that is necessary to mix the fresh sewage with the activated sludge, just as the ascending bubbles of air in the air diffusion process produce agitation. Likewise, the great change of surface that is essential in obtaining oxygen for the oxidizing bacteria is obtained by mechanical aerators in a manner similar and apparently equivalent to the change obtained when agitation is induced by air bubbles. Studies seem to indicate that most of the oxygen is obtained from the atmosphere in the air-diffusion process rather than from the ascending bubbles. This indication was borne out by the great improvement in the air-diffusion process when the spiral flow was introduced, and also by the experiments of the two English engineers, Haworth and Hodgkinson, *Municipal News and Water Works*, (May, 1929), who found that the absorption of oxygen by sewage continued to take place after they substituted nitrogen gas for air at the diffuser plates.

At the present time there are several methods of obtaining mechanical aeration, among which are the Haworth paddle, the Hartley paddle, the Simplex aerator and the Link-Belt aerator. So far as is known, the only permanent plants in the United States depending upon mechanical aeration to produce activated sludge are employing Simplex aerators, and most of the plants in England are Simplex plants. Complete descriptions of all methods, including data on analytical results and power costs are to be found in "The Activated Sludge Process," a recent book by A. J. Martin, and in a comprehensive article in the May, 1929, issue of *Municipal*

[1] *Presented at the Second Annual Meeting, Central States Sewage Works Association, Indianapolis, Ind., June 20, 1929.*

[2] *Shields, Jordan and Roe, Engineers, Chicago.*

News and Water Works, by W. D. Vosbury and P. B. Streander. The writer has presented papers at the last two meetings of the Illinois Society of Engineers on the construction and operation of the Princeton, Illinois, plant, abstracts of which appear in the current issue (June, 1929) of *American City Magazine.*

The Princeton plant is designed to care for $^1/_2$ million gallons per day dry-weather flow. It consists of a grit and coarse-screen chamber, a preliminary settling tank with a one-hour detention period, five aerating units with an eight-hour detention period during the sixteen-hour maximum flow, and a final settling tank having a theoretical detention period of two hours. All tanks are uncovered and are of reinforced-concrete

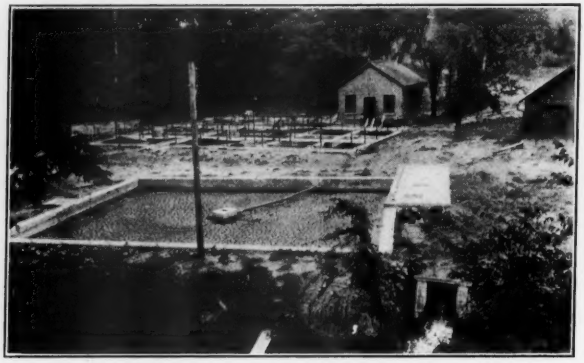

FIG. 1.—View of Plant from Outfall.

construction, treated with two coats of a bituminous waterproofing. A pump house of brick construction contains two double-acting plunger pumps for pumping sludge, a wash-water pump, a sludge division box, and electrical control equipment. The old septic tank on the site was converted into a separate sludge-digestion tank and the old filter bed into a sludge drying bed. Both of these units are considerably undersized, the digestion tank having a capacity of only $1^1/_3$ cubic feet per capita and the drying bed an area of only $^1/_2$ square foot per capita.

Sludge is collected in the flat bottomed preliminary tank by means of two flights of Link-Belt sludge collectors and pumped from the hoppers directly to the sludge digestion tank. The settled activated sludge in the final tank is likewise collected by two flights of Link-Belt sludge collectors and is pumped from the hoppers to the division box in the pump house. The greater portion of the sludge is separated here to flow by gravity to the first aeration unit as return sludge. The remainder flows to

the digestion tank where it mixes with fresh solids from the preliminary settling tank. The percentage of sludge to be returned to the influent is regulated by a movable partition on the face of a weir in the sludge division box.

A feature of the plant is flexibility of operation. Either preliminary or final settling tanks may be by-passed in case of a breakdown, and the first or last aerating tanks used for settling purposes, since there is a suction pipe connected to the pumps from the bottom of each tank. Any of the aerating tanks may also be cut out. No interruption in operation because of equipment failure or breakdown has been necessary thus far, however, and the possibilities of such interruptions seem very remote at this time.

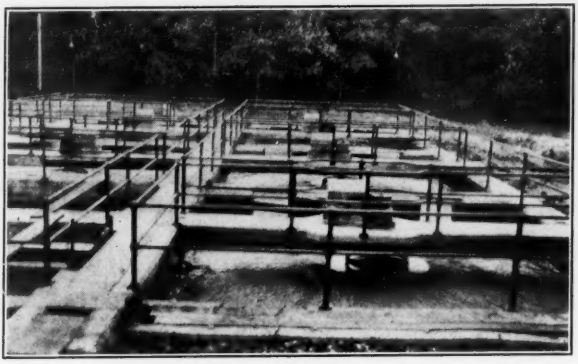

FIG. 2.—Five Simplex Aerators.

A temporary overflow weir is provided to care for the excess ground water infiltration following a storm. Princeton expects to reconstruct and add to its storm water sewer system which will relieve the territory now causing excessive infiltration.

The city constructed a seven-room house on the premises and a local man was engaged as operator. A great deal of landscaping has recently been completed which adds considerably to the appearance of the plant. A rain gauge and registering thermometer have been the latest additions.

Operation of the Princeton plant began January 20, 1928, and has been continuous since that time with the exception of two or three interruptions of a few hours when the power was off. Notwithstanding the fact that zero weather was encountered during the first few weeks, the sludge built up rapidly and a stable effluent was produced. No troubles were encountered as a result of the formation of ice on the aerators or tank

structures. Any ice forming was removed daily for the sake of appearance. The warmer months of 1928 brought improved results and conditions favorable to a better study of the plant. Measurements of the sewage flow have been taken four times daily since the plant started, and the wide range of flow recorded indicates the most serious difficulty to be met in the operation of the plant. During the early spring of 1928, flows were recorded as high as 1.5 m. g. d. after rains, and the average flow up to May, 1928, was about 700,000 gallons per day. Since the plant was designed for a capacity of one-half million gallons per day it is apparent that such an overload could not be carried continuously. Consequently the overflow weir between the preliminary settling tank and the aeration tanks has been kept adjusted to allow all sewage over about 500,000 gallons per day to be discharged directly to the creek, although at times as much as 750,000 g. p. d. were treated. This excess sewage, however, has the benefit of effective preliminary tank treatment. Between May 1 and Nov. 1, 1928, practically the entire flow was treated except during a few periods of heavy rains, particularly in July. The average flow during that period was about 600,000 g. p. d. the minimum being 308,000 g. p. d.

These data on quantity of sewage flow are the averages of readings taken over a rectangular weir at 6 a.m., 10 a.m., 2 p.m. and 6 p.m. and are consequently not as accurate as desirable. A proportional weir and recording and intergrating flow meter were installed in May of this year, and accurate readings are now being obtained.

A survey of the sewer system was made early in the year 1928 and some relief from infiltration and admission of surface water into the sewers effected. It is hoped that this work will be carried on in conjunction with the construction of additional storm sewers, to the eventual abolition of all excess water from the sanitary sewers.

The preliminary settling tank has given very satisfactory results, although the Link-Belt sludge collecting equipment was hard to start during cold weather due to the high viscosity of the oil in the planetary reduction gear case. This tank has been removing an average of 43 per cent of the total suspended solids. The aeration units have also been very satisfactory in building up and maintaining a typical activated sludge. The aerators have been raised $^1/_2$ inch since operation began, with quite an appreciable saving of power as a result and without any apparent falling-off of analytical results.

The final settling tanks have not given any better results than the average run of activated-sludge settling tanks in other cities. Some colloidal matter and finely-divided floc have been noticed flowing over the final effluent weir. The entire return run of the flights or scrapers of the Link-Belt collecting equipment in these final tanks was raised to a plane just

below the flow line, instead of returning from the top at the inlet end of the tanks to the bottom at the effluent end, as has been customary practice. This change brought about the apparent reduction of a current at the bottom of the tanks and a slight reduction of floc going over the effluent weir. Additional weir length at the outlet of these final tanks would undoubtedly be of benefit because of the reduced velocity of the effluent toward the weir.

Since the digestion tank is the adaptation of an old septic tank to another use, it was expected that it might be difficult to obtain good results, but thus far all sludge has been well digested and odorless. It has dried readily to a typical stable and odorless cake on the drying bed. The tank was not seeded with ripe sludge nor has any lime been added to the sludge at any time to control the pH. Odors are not perceptible near the tank, due to the old brick building which covers it. There is not much scum

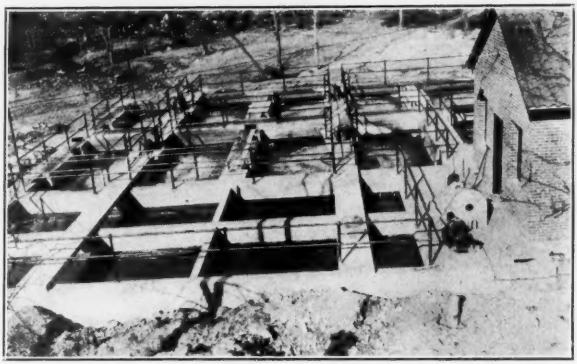

FIG. 3.—Aerating and Final Settling Tanks.

on the liquor surface and what there is does not prevent the gas from escaping freely, which is probably due to the fact that the scum is agitated and hosed thoroughly once or twice a week.

The small size of the Princeton plant did not warrant the construction of a chemical laboratory but methylene blue stability tests have been run daily since the plant started. Except for two periods of about five days each, every sample has stood up for at least ten days and more than 90 per cent of the daily samples have been blue after twenty days. The two periods mentioned were due, in the first case, to a large quantity of septic sludge released from lodgment in the sewer system by an increase in flow; and in the second case, to a like quantity of sludge from the digestion tank overflow, caused by the operator failing to close the particular inlet gate directly below the overflow in use at that time.

Five series of tests on 24-hour composite samples have been run under the direction of H. F. Ferguson, chief engineer of the Illinois State Department of Health. The first four were run previous to May, 1928, and would be indicative of conditions during periods of excessive flow except for the fact that normal conditions did not exist when the plant was started. The following table gives the average of the results on raw sewage and on final effluent for the first four tests.

RESULTS IN PARTS PER MILLION

	Raw Sewage	Final Effluent
Suspended solids	43	19
Free ammonia and organic nitrogen	14.48	10.46
Nitrites and nitrates	2.48	4.10
Oxygen consumed	52.3	29.1

The five-day biochemical oxygen demand on the final effluent was, in the order of the tests, 27.5, 12.25, 4.2 and 5.0 (all results expressed in parts per million).

It is to be noticed that an unusually dilute sewage was treated prior to May, 1928, due to infiltration of ground and surface water. During the following dry weather, however, with a sewage containing suspended solids in excess of 100 p. p. m. entering the plant the results did not fall off, but improved. This was due to the fact that, as the quantity of sewage dropped, the concentration of activated sludge consequently increased to and above the concentration found to be optimum, thus permitting an excess to be sent to the digestion tank for the first time since the plant was started. Moreover, the condition of the sludge improved with the increased period of aeration, and remained so even though the sewage flow fluctuated later.

A complete daily record is kept by the operator and mailed as a report to the State Department of Public Health, at the end of each month. The tabulations are for: rainfall, temperatures, sewage flow (total and aerated), power consumption, quantity of screenings, sludge pumping, sludge return, settleable solids and stability.

The power used for the aerators alone previous to their being raised, averaged 174 kw. hrs. per 24 hours. Since raising the mechanism the average has been 144 kw. hrs. per 24 hours. The power requirement varies with the rate of sewage flow since there is no way to raise the aerators automatically as the flow of sewage increases, and to lower them as the quantity decreases, nor is it practicable to vary their speed.

Assuming that the quantity of sewage being handled is equal to the capacity of the plant, or $^1/_2$ m. g. d. the power requirement now is at the rate of 17.5 horsepower per million gallons. Previous to lowering the aerators, and with the plant operating at capacity, the requirement was 19.6 horse-

power per million gallons. The total average consumption at present for aerators, pumps and collecting apparatus is 220 kw. hrs. per 24 hours, equivalent to 24.6 horsepower per million gallons.

The bar screen is cleaned four times each day, the screenings averaging $^1/_2$ cubic foot per day.

The removal of sludge by the preliminary tank has varied considerably in volume due to varying periods of pumping, but has averaged 2250 gallons per day.

A daily determination of the sludge concentration of the liquor in the aeration tanks is made by the usual one-hour settling test in a graduated cylinder. This concentration has been maintained close to 17 per cent after it had attained that figure about May 1, 1928, although experiments made during the past year indicate that satisfactory results may be obtained with a concentration of 15 per cent. The excess activated sludge is discharged regularly to the digestion tank along with all of the fresh solids from the preliminary tank. The quantity of activated sludge returned from the final settling tanks to the first aerating unit has been increased lately from 25 to 35 per cent of the total quantity of sewage flowing through the plant, with slightly improved results.

The writer's firm has been employed to supervise the operation of the plant, which obviates most of the disadvantages of having a non-technical man as operator. The ability and resourcefulness of the operator has been improving steadily, however, and there is no reason why the present arrangement should not continue with satisfactory results. The attention given by engineers of the State Department of Public Health and by the service men for the Simplex Aerators, has served to educate the operator in his duties to a great extent.

The average annual cost of operation cannot be determined accurately at this early date but it will probably be about as follows:

Power, 79,200 kw. hrs. at $0.025 per kw. hr.	$1,980.00
Labor, operator at $100.00 per month	1,200.00
Miscellaneous supplies, telephone, etc.	150.00
Cleaning drying beds	150.00
Total	$3,480.00

Assuming the average sewage flow treated for the year to be at the rate of 0.45 m. g. d., the cost of operation, excluding repairs, depreciation and fixed charges would be about $21.00 per million gallons treated.

The financial feasibility of this type of plant, its characteristic freedom from odors and the assurance of having a full-time operator, mark it as quite desirable to almost any community below the large city class.

II. Sewage Treatment Plant, Lemoore, California[1]

BY C. C. KENNEDY[2]

This paper presents a brief description of the sewage treatment at Lemoore, Kings County, thirty miles south of Fresno, California.

The plant, completed in October, 1928, but closed down at intervals due to mechanical difficulties, has been operating continuously for about three weeks since its completion.

Lemoore has a present estimated population of 1750 and is located in the Tulare Lake basin. The topography is practically level so that low grades and sluggish flow characterize the collecting system.

The sewage is a combination of domestic sewage and creamery waste, the effective treatment of which is, obviously, a difficult problem. Suspended solids are low, average 170 p. p. m., but the biochemical oxygen demand varies from 165 to 1000 p. p. m., most samples containing milk waste being between 600 and 700 p. p. m. The milk waste is contributed by two large creameries. The average daily sewage flow amounts to 310,000 gallons per day.

The earlier plant consisted of an enclosed box-type septic tank located inside the corporate limits followed by a pumping plant and pressure line to the disposal site, 6500 feet southerly. This site was really only a point of discharge from which the sewage flowed through an open ditch to lands below where it was permitted to pond and was used intermittently for irrigation. The odor from the pumping plant, which was located immediately opposite a school, was noticeable for a distance of 1000 feet, while the odors along the ditch were strong for a distance of 2 miles below the plant. Flies, breeding in the ditch, caused the closing down of at least 2 dairies below.

Realizing the difficulty of the problem, an experimental investigation was started in May, 1927. Based on the available experimental data, treatment by activated sludge, filtration through a lath filter, and a combination of both, was determined upon.

The activated-sludge plant consisted of a small Simplex unit, with a runner 2 feet in diameter at the top, mounted in a tank built in the shape of the frustrum of a 4-sided pyramid, 15 in. square at the bottom, 8 ft. 6 in. square at the top, and 4 ft. 6 in. deep. In order to secure comparative quantitative results, the runner was run at such speed as to give the same peripheral velocity as a full-size Simplex unit operated at 60 revolutions per minute. This gave a turn-over of 45 gallons per minute in the tank of 1000 gallons capacity.

[1] *Read at Spring Conference, California Sewage Works Association, Fresno, March 20, 1929.*

[2] *Consulting Engineer, 543 Call Bldg., San Francisco.*

The filter was built of lath laid checker-board fashion, 8 ft. long, 4 ft. wide and 4 ft. deep, with a wood floor sloping to a collecting trough at one end. It was dosed by means of a tipping-can arrangement, discharging into 2 distributing pipes.

The plant was first set up near one of the creameries and operated on creamery waste. After six weeks in this location it was demonstrated that a clear, odorless effluent with 5-day stability could be produced. The plant was then moved to the existing site of the septic tank and there operated for sixty days on the mixed domestic sewage and creamery waste, in order to obtain quantitative results for use in design. Various periods of aeration were tried out, with varying volumes of sludge. The unit was operated for two months on the fill-and-draw and continuous-flow methods, both with and without subsequent filtration of aerated sewage at various rates. Stabilities of from 6 to 12 days were secured with aeration periods of 4 hours or more, using 25 per cent of sludge. When followed by filtration at rates up to 5 million gallons per acre daily, the stability was increased to 20 days or more.

In February, 1928, a second series of tests was run with the experimental unit to determine the reduction in biochemical oxygen demand on the tentatively adopted balance of design between aeration (activated sludge) and filtration. The results obtained after only 2 weeks' operation are shown in the following table:

	B. O. D. p. p. m.
Raw sewage	650
After 4 hours' aeration and 1 hour settling	205
Settled effluent on trickling filter at rate of 6 million gallons per acre per day	44
Settled effluent on trickling filter at rate of 4 million gallons per acre per day	27

On the basis of these experimental data, the plant design was finally fixed.

The plant site chosen was the tract owned by the City of Lemoore, previously mentioned as the point of discharge of the old pressure line. This area consists of 2 tracts, of 10 and 20 acres, respectively. The soil is sandy with the water table only a few feet below the surface of the ground.

As a part of the reconstruction work a new gravity line 15 inches in diameter replaced the worn-out 6-inch pressure line and the pumping plant was moved to the treatment plant site.

The plant consists, therefore, of fixed bar screens with $^3/_4$-inch openings, followed by 3 pumps, each with a 4-inch discharge, single port, non-clogging runner, with a design capacity of 225–250 gallons per minute against a total head of 35 feet.

These pumps discharge directly to the aeration units, 4 in number, equipped with Simplex mechanical aerators, so arranged they can be oper-

ated in series or with the first unit operated as a reconditioning unit for the sludge. Provision is also made for bypassing any unit.

Each aeration basin has a volume of 30,000 gallons, so that when using three units an aeration period of over 4 hours is provided for the design flow of 264 gallons per minute, when carrying as much as 40 per cent of returned sludge.

The sewage flows from the aeration units to a sedimentation basin 25 ft. square with corners filled, the side water depth being 10 ft. The effective volume of the settling basin is 5570 cubic feet. This volume allows a detention period of 2 hours for the design flow when carrying 40 per cent of returned sludge.

The effluent from the sedimentation basin flows into the siphon dosing chamber and thence to a trickling filter. The filtering medium is rock, with an effective area of 3900 square feet and a depth of 6 feet. This gives a filtering rate of $4^1/_4$ million gallons per acre per day for the design flow.

Sludge drying beds having an effective area of 15,000 square feet were constructed by throwing up levees around the native soil, which is a sandy loam.

Discussion.—Mr. Kennedy added that the water supply at Lemoore is highly charged with sulphur compounds and is devoid of oxygen. The sewage as it reaches the plant is acid, but the pH of the sprinkling filter effluent is 7.4, on the alkaline side. Sludge from the aeration tanks and from the secondary clarifier was acid and when discharged to beds seemed an ideal breeding place for flies, which multiplied by millions. Reconditioning of sludge and treatment with lime gave non-odorous sludge which dewatered more quickly than acid sludge. Whether it will become acid again in hot weather is one of the things to be determined.

The Simplex aerator units, instead of being set on piles, are constructed as a unit on a concrete mat, so that if they settle or tip they will do so uniformly.

Some troubles were experienced with the driving mechanism.

No preliminary settling or sludge digestion was provided because the sewage contains very little settleable solids and it was felt that retention in primary tanks would aggravate fermentation in this highly-fermented waste. It was hoped that it would be unnecessary to provide sludge digestion in view of the results obtained at Lodi. If the problem can be solved without the use of digestion tanks, considerable expense will be saved.

The present problem is to eliminate odors. Some odors come from the aeration tanks and whether they can be eliminated by changes in operation, or possibly by pretreatment with chlorine in the sewer before the sewage reaches the plant, are problems which require study. Some odor comes from the sprinkling filter but the major portion has been from the sludge beds.

The plant is giving a very satisfactory reduction in biochemical oxygen demand, and the effluent is good, allowing for the present unloading of the filter.

The problem should be of interest to members of the Association, particularly those who have had anything to do with milk wastes.

Mr. Roberts, of Mr. Kennedy's office, stated that he had been at Lemoore for 3 or 4 days and practically eliminated odors from the aeration tanks and sprinkling filter although some sludge beds which had acid sludge dumped on them still produced odors. Some good sludge and some acid sludge is on the beds and the difference can be noticed immediately. The problem cannot be neglected because control of operation is 95 per cent of the success of the plant.

Mr. Hammerly with the aid of drawings showed the principle of the operation of the Simplex aerators, which consist of a revolving disc, 5 ft. in diameter, with blades very much like a centrifugal propeller in a pump, set over a vertical uptake tube 4 ft. in diameter which reaches to a point near the bottom of the hopper-bottom tank in which it is placed. The vertical velocity in the uptake tube is about 3 ft. per second, and the pumping capacity at 65 r. p. m. approximately 1200 gallons per minute. Mechanical difficulties have been corrected by providing stiffer bases for the driving mechanism than those originally installed.

Simplex Plant at Lawton, Oklahoma.—Col. Webster L. Benham has recently described the features of design of a newly constructed Simplex activated sludge plant at Lawton, Oklahoma. This plant consists of a gate house, bar screen, preliminary settling tank with 1-hour detention period, nine aeration tanks providing a period of 8.0 hours, one sludge re-aeration tank with a period of 4.8 hours at a rate of 140 gallons per minute and one large Dorr tank for final settling with a 2.5-hour detention period. The sludge is disposed of by digestion and drying on sand beds.

The ten Simplex cones are geared to revolve at 50 r. p. m., and each is driven by a separate motor. The approximate power requirements are estimated at 1.8 H. P. per unit.

The plant was designed for an average flow of 1.0 m. g. d. from a population of 15,000. After operation was started on June 15, 1929, it was found that the sewage reaching the plant was diluted with an abnormal amount of ground water, and that it contained considerable grease and some creamery wastes.

The separate sludge digestion tanks provide a capacity of 3.75 cu. ft. per capita for all sludge, both settled and activated.

The cost of the complete plant and outfall sewer was $115,000. *Public Works*, **60**, 302, August, 1929.

Design and Operating Features of Sewage Treatment Works near Habitations, Particularly at Whitemarsh Valley Country Club and Wawa Dairy Farms[1]

BY FRANCIS S. FRIEL, M. AM. SOC. C. E.[2]

It is a well-known fact that practically no sewage treatment plant is operated throughout the entire calendar year without odors. If a plant is far removed from habitation no one is annoyed by a disagreeable smell, but if it is located near a populous district a nuisance is created immediately. It is, therefore, the duty of the engineer who designs sewage treatment works, to be located near a community, to use extreme care in the selection of the method of treatment; and after the plant is in use, it should be properly operated.

Good operation is equally as important as good design. It is quite true that some operators have a just cause in their complaint that the engineer designs and builds the plant, and then forgets it. The designing engineer should supervise the operation of a plant for at least a year after it is put into service. Then again, the responsible authorities, public or private, have the opinion that the problem is solved when the sewage plant is completed. This is unfortunate, as in many cases the man selected as the operator is underpaid and is assigned to one or more positions, so that the sewage plant work is neglected.

If a treatment works is to perform the duty for which it is designed, namely, the clarification of sewage with a minimum odor and the elimination of stream pollution, it must be run on a basis similar to that of any successful business. No operator can afford to neglect his plant. It must receive daily attention and should be handled so that each unit performs its specific duty with the highest degree of efficiency.

In presenting an example of the design and operation of sewage treatment works near habitation, I have selected the institutional plant for it usually is more difficult to select a remote site for an institutional sewage plant than it is in the case of a sewage works for a municipality. One of these plants is located at the Whitemarsh Valley Country Club near Philadelphia, and the other at Wawa Dairy Farms near Media, Pennsylvania. The two plants are similar in design, location and importance of operation, so that I will only describe in detail the features of the plant at Whitemarsh Valley Country Club.

This club lies on the watershed of the Wissahickon Creek immediately adjacent to Philadelphia. It has a membership of 540 persons and during the golf season many important local and national tournaments are held there.

[1] *Presented at Third Annual Conference Pennsylvania Sewage Works Association, Harrisburg, Pa., July 17, 1929.*

[2] *With Albright and Mebus, Consulting Engineers, Phila., Pa.*

In order to eliminate the overflowing cesspool nuisance, it was decided to construct a sewage treatment works. The only available site for such a plant was located within one hundred feet of the locker room and within three hundred feet of the club house, and the creek below this site flowed through the golf course. It was, therefore, essential that the sewage treatment works be inoffensive, pleasing in appearance and capable of producing a highly purified effluent. It was necessary also to provide for the peak flow of a summer week-end when 200 to 400 persons are at the club, and for the minimum discharge of the periods when only 25 employees are contributing to the sewage works.

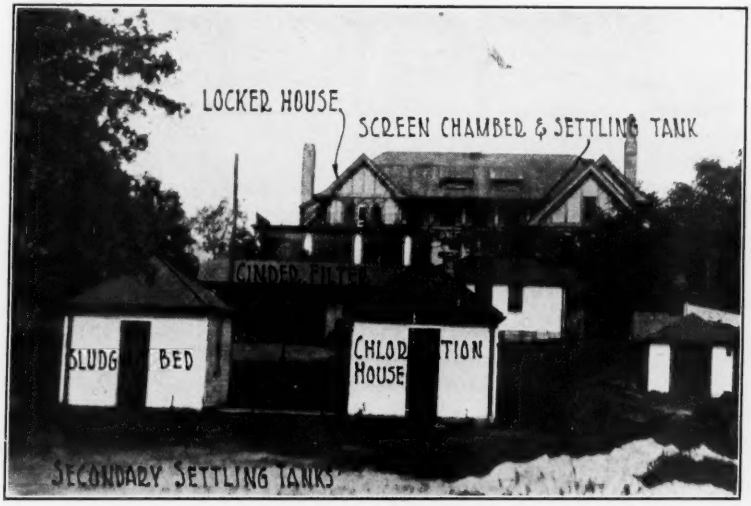

FIG. 1.—Sewage Treatment Works, Whitemarsh Valley Country Club.

To comply with these requirements, it was necessary to provide complete treatment. It was a simple matter to enclose the settling and resettling tanks and likewise the sludge bed; but the chief concern in the design was to produce an oxidizing agent which would eliminate the nuisance of sewage flies and odors usually noted near a sand or sprinkling filter. The installation of an activated sludge plant was out of the question because of the small flow. It was, therefore, decided to construct a filter which would prevent the sewage from being exposed to the atmosphere and to view. It will be seen that this design presented an unusual engineering problem.

Design

The plant constructed in 1923 consists of a grease trap on the kitchen sewer, a screen chamber, a two-story settling tank of the Imhoff type with

a separate sludge compartment, a filter, a chlorination unit, resettling basins and a sludge drying bed.

The screen chamber and Imhoff tank are housed in a small building. The screen consists of a galvanized wrought iron bar screen with $1^3/_4$-inch clear openings. The settling compartment of the Imhoff tank was designed for a theoretical 1.41-hour flowing-through period under maximum conditions, a 5.25-hour detention for minimum flows, and a 2.31-hour rate for average summer conditions. Sludge storage was provided for the average summer population at the rate of 2.0 cubic feet per capita. An unusual feature in the design of the tank includes an adjustable galvanized-iron outlet weir. This plate has a row of one-inch holes drilled 12 inches below its crest. During minimum flows the sewage is discharged through the holes, while at times of peak-load conditions the level rises so that a portion of the liquid flows over the crest of the weir. It also has a 12-inch adjustment. In the summer months it is raised to its highest level, thus providing additional settling capacity, and in the winter it is lowered 12 inches in order to secure the minimum retention period in the settling compartment. An auxiliary sludge chamber was provided adjacent to the Imhoff tank for the purpose of drawing off sludge for treatment in case of a foaming tank.

The oxidizing device is a filter with a depth of 7 feet below the distributors. The medium in the lower 2 feet of the bed is trap rock and the specifications for the upper 5-foot layer of material called for hard coal cinders which would be retained on a screen with four meshes to the inch. The bed is underdrained with open tile lines and similarly the sewage is distributed upon the cinders by a system of vitrified pipes laid with open joints. The distributing lines are covered with a layer of cinders 12 inches deep so that no pipes are exposed to view. The sewage is discharged intermittently onto the filter from an automatic siphon chamber.

To obtain the maximum efficiency with this type of bed, the sewage must be evenly distributed. This is accomplished by spacing the laterals about 2 feet on center, and by designing the capacity of the siphon chamber to equal the cubical contents of the distribution system. In the selection of the filter media, it is most important to secure cinders which will not break down. Only cinders burnt from hard coal should be used, and before they are placed upon the bed they must be thoroughly screened, and washed at least twice. Another point of importance for successful operation is the removal of grease from kitchen waste before it is discharged into the sewers.

The most important factor to be considered, however, in the design is the rate of filtration. At Whitemarsh the average rate (these data have been taken from operating records) has been 217,000 gallons per acre per day. During the maximum flow periods the rate has probably been increased to 500,000 gallons. From my experience at Whitemarsh and at

other similar installations, I do not believe a filtration rate of 250,000 gallons per acre per day based upon average flow conditions should be exceeded in the design of a cinder filter. Furthermore, it is my opinion that this type of filter would not be adaptable for the larger municipal plant.

After leaving the cinder filter, the sewage flows to the chlorination chamber where it is treated with liquid chlorine. It then passes through a secondary settling basin and the final effluent is discharged into Wissahickon Creek. The secondary settling basin is subdivided into two compartments, each designed with a one-hour retention period for the average summer flows. These basins are covered with a concrete slab and admittance is gained through manhole doors.

The sludge from the Imhoff tank drains by gravity to a covered drying bed, and the secondary settling tank sludge is lifted onto this bed by means of a hand boat pump. The filtrate from the sludge bed drains to the lower portion of the cinder filter so that it is mixed with the sewage and is treated with chlorine before it reaches the creek. A total head of 14 ft. 6 in. is required to pass sewage through the treatment plant.

Landscape development is an important feature in the design of a plant near habitation. At Whitemarsh this is especially true, consequently much care was exercised in making the surroundings pleasing in appearance. The houses which enclose the Imhoff tank, chlorination room and sludge bed were designed to harmonize with the architecture of the club buildings, and the sewage works area was artistically graded and planted with evergreens and flowering shrubs.

Operation

The operating results obtained at Whitemarsh indicate that the sewage works has been producing a splendid effluent and has not been offensive. We have never had a complaint about odors and this I feel is a tribute to the success of the plant. The effluent is clear and sparkling. Putrescibility tests of the filter effluent are run daily and the time for decoloration has averaged ten days. The sewage works at Wawa Dairy Farms has produced results equal to those obtained at Whitemarsh.

Settling Tank Operation.—I have previously stated that a sewage treatment plant should be operated so that each unit performs its specific duty with the highest degree of efficiency. The first step in treatment, namely, the settling of suspended matter and the subsequent sludge digestion, is the most important phase of clarification, and a tank to perform this function should receive the greatest care. Domestic sewage decomposes readily; it putrefies after standing a few days even when the solids have been removed. The dissolved and colloidal organic substances, which in quantity about equal the solids, are responsible for this condition.

In the operation of a plant such as described herein, it is essential that

the settling tank be efficient so that a high percentage of solids will be removed. To determine the efficiency of a settling tank, samples of the influent and effluent should be collected and the percentage of removal ascertained. At Whitemarsh these tests are made each day and the results of such analyses indicate from 95 to 98 per cent removal of settleable solids.

In addition to the care of the settling compartment, whether a plant is of the Imhoff or separate sludge digestion type, the operator should be acquainted with the characteristics of sludge, the difference between acid and alkaline fermentation, the reasons for scum formation and when sludge is ripe and ready for withdrawal. If a tank near habitation is to be properly operated the man in charge should be thoroughly familiar with these conditions and for this reason, I will touch briefly upon their peculiarities.

Characteristics of Sewage Sludge.—In plant operation, examination of sewage sludge is concerned chiefly with its color, odor and water content and the ease with which it can be dewatered. Fresh sludge is gray or yellowish in color and contains readily recognizable pieces of fecal matter, paper and vegetable debris; it has a foul odor and is dewatered only with difficulty. The sludge liquor is turbid and foul-smelling and within one day acid fermentation commonly sets in.

Well-digested sludge is black and has a tarry odor, or smells like burnt rubber. During good weather, it becomes spadable in about ten days, in layers 8 inches in thickness. The biological character of the sludge is best indicated by its pH value (its hydrogen-ion concentration)—a measure of its acidity or alkalinity. Thoroughly digested sludge is alkaline; that is, it has a pH value above 7.0. The sludge liquor is clear and without disagreeable odor.

Well-digested sludge gives up its moisture rapidly, dries readily and does not produce odors during drying. Fresh sludge dries slowly and gives off unbearable odors.

Acid Fermentation.—When fresh fecal solids are allowed to decompose under water, the gases first produced are principally hydrogen, carbon dioxide and odoriferous gases. The reaction of the sludge, originally neutral, quickly becomes acid, and its pH value sinks approximately from 7 to 5. This type of fermentation, resulting from a number of concurrent processes, is called acid fermentation. Its appearance is extremely undesirable in sewage treatment works, because it proceeds very slowly and decreases the sludge volume scarcely any. Furthermore, it does not render the sludge easy to dry and, on the other hand, imparts to it most objectionable odors that arise particularly during motion of the solids. The sludge is yellowish gray, sometimes greenish, in color and is sticky. Since it entraps gas bubbles, it is foamy and is apt to rise as surface scum. When this kind of sludge is exposed to the air it can be identified, apart from its

odor, by the fact that there hover about it large, yellow sewage-flies that are not found on well-digested sludge.

Alkaline Fermentation.—Basically different from acid fermentation is the second kind that establishes itself in well-conditioned digestion tanks. It results in the formation of carbon dioxide, nitrogen, and, above all, methane (marsh gas), the latter constituting at least 75 per cent of the gas by volume. The pH value consistently remains slightly above the neutral point. The process is odorless and is called alkaline fermentation.

All sludge-digestion tanks, treating strictly fresh sewage solids, must pass through an initial period of acid fermentation. If the sewage and sludge are fresh, the time consumed, at an average temperature of 60° F., before ripe sludge can be drawn is about five months. Digestion tanks may be broken in artificially, by the addition of hydrated lime. The quantity of lime introduced, however, should be restricted so that a pH value of 8 is not exceeded. In order to maintain alkaline conditions, liming must be repeated at frequent intervals.

Ripening.—The natural process of sludge ripening in digestion tanks starts at the bottom and gradually spreads through the entire sludge mass. Gasification lifts sludge particles that have become enriched with methane fermentation; these particles ascend to the water surface where they mix with others that have not yet been seized by alkaline fermentation; after giving off their gases, they finally sink back to the bottom. The sludge mass, therefore, is in a state of constant circulation. This allows the agents of fermentation to draw new nourishment continually from the freshly deposited solids and to "inoculate" or "seed" incoming sludge. Fresh solids, furthermore, should find their way into digestion compartments uniformly and in such small quantities that the old, alkaline sludge masses will always control the processes of fermentation. Large quantities of fecal matter, such as that removed from a privy, should never be dumped into a settling tank. Acid fermentation spreads through the entire mass in a few days, whereas alkaline fermentation progresses slowly, and is certain to overcome acid fermentation in the end. Once a tank is broken in, therefore, acid fermentation should not reappear, provided mistakes in operation are not made.

Scum Formation.—The layer of scum that covers the surface of sludge-digestion tanks or gas vents does not afford the conditions requisite to proper methane fermentation. Even after months have elapsed, fecal matter that has found its way into the scum and remained there can still be noticed in process of acid fermentation, and nearly unchanged in structure. Scum layers that contain undecomposed solids in large quantities should, therefore, be broken up. This is best done with the aid of a jet of water. In well-operating digestion chambers, the scum should consist only of digested sludge particles. It is good practice to keep the scum

broken up and submerged, for in this way scum formation can be reduced to a large extent.

The importance of effecting a high removal of solids in a settling tank and of controlling sludge in a digestion tank has been stressed. The practical way for the operator to accomplish this is:

First, clean screen at least once each day.

Second, if it is an Imhoff-tank installation, clean sides and slopes of settling compartment at least twice weekly.

Third, a daily removal of the floating material in the sedimentation chamber.

Fourth, scum which forms in the gas vent should be broken up at least once a day.

Fifth, observe the depth of sludge once each week. This may be done by means of a pitcher pump with an ordinary garden hose suction, or with a square iron plate attached to a light wire or chain.

Sixth, run daily analyses to determine the efficiency of the settling compartment and the pH value of the sludge.

Seventh, in Imhoff tanks, sludge should not be allowed to accumulate to a level within eighteen inches below the slots of the settling compartment.

Eighth, keep the place clean.

Sprinkling Filter.—When sewage leaves a settling basin it contains dissolved and colloidal organic substances which about equal the quantity of solids settled out in the tank; and treatment in a biological device is necessary in order to make it stable. This step in treatment is called oxidation. The usual methods are by means of trickling filters, contact beds, sand filters and activated sludge. The cinder filter at Whitemarsh is similar in function, and differs only in the media employed and the distribution system. The object of this unit is to reduce the oxygen demand of the liquid until the effluent remains stable. Sewage becomes stable when its total oxygen content, either in the form of dissolved or available chemically combined oxygen, at least equals the quantity needed by the bacteria for the destruction of the organic matter present without putrefaction. The treatment of sewage in a filter is accomplished by the filter media becoming covered with slimy organic films in which purification proceeds by the action of microörganism in presence of oxygen.

Filter odors are best controlled by keeping the sewage as fresh as possible during preparatory treatment. To obtain the maximum efficiency of any of these beds, sewage should be evenly distributed, which means the pipes must be kept clean. Pooling should be prevented. At Whitemarsh pooling of a small portion of the cinder filter has occurred once in the five years the plant has been in operation. This condition was remedied by digging up that section of the bed 12 inches below the distribution lines, and by washing the cinders and cleaning the pipes in the area affected.

The efficiency of a filter is best determined by observing the color of the growth in the underdrainage system and by running putrescibility tests. If a green growth appears it is a sign that the bed is functioning properly, whereas, if a grey color is noted it indicates trouble, and the cause is usually poor distribution.

Chlorination.—The only chemical process of importance at present in sewage treatment is chlorination. The most effective method of disinfection is by the application of liquid chlorine. The plant attendant should determine whether or not sufficient chlorine is being added and this may be done by the simple orthotolidin test which will indicate the presence of free or excess chlorine in the final effluent. Chlorine will destroy disease-producing organisms and within certain limits will render the sewage more stable.

Secondary Settling.—Secondary settling tanks are required after chlorination, if complete treatment is to be accomplished, that will provide sedimentation equivalent to a retention period from one-half to one hour. These basins should always be installed in duplicate. The sludge from a secondary settling tank is difficult to dry and in some instances it has been returned to the sludge compartment of the preliminary settling tanks for digestion. Drying of sludge from a secondary tank is hastened by mixing it with sludge from the preliminary tank.

Sludge Drying Beds.—If the sewage plant is located near a community the sludge bed should be covered with a glass enclosure similar to hot-house construction. In designing a covered sludge bed, area should be provided at a rate of from one-third to one-half square foot per capita. In drawing sludge it is not advisable to cover the bed to a greater depth than 12 inches. In from ten days to two weeks the sludge should be dry enough to remove, and this removal should be carried out promptly.

Landscaping.—An important feature which is often neglected around sewage plants is the beautification of the surrounding grounds. This should be done for psychological reasons if for no other. It is money well spent to grade the grounds artistically and to plant flowers, evergreens and shrubbery. I am thoroughly convinced of its importance, especially for a sewage works located near a populous district.

Conclusion

In conclusion I wish to remind the engineer that his design should meet the local requirements. Every detail worked out to lighten the burden of the operator will be appreciated and will be an incentive to faithful care. It is also urged that the plant attendant keep a complete operating record of the sewage works, so that the designer may be informed of the results of his efforts.

Editorial

Complete Treatment of Sewage

From a practical standpoint it is impossible to treat sewage completely, that is, to remove one hundred per cent of the putrescible matter. Even from a purely theoretical standpoint it is impossible to oxidize all of the organic matter by biological agencies, and under any circumstances the end-products of oxidation remain in solution in the effluent.

Notwithstanding these facts the biological oxidation of sewage is generally termed complete treatment, whether the process be trickling filters, activated-sludge or intermittent sand filtration. Before the development of the activated-sludge process it was customary in this country to use trickling filters for complete treatment on a large scale and intermittent sand filters where natural conditions permitted their use, usually for small-scale projects. The difference in degree of treatment effected by these two processes was well recognized, but in view of the immense areas required for intermittent sand filtration on a large scale, it was becoming evident that the possibilities of complete treatment on a large scale would be limited by the efficiency of well-operated trickling filters. This situation limited the degree of treatment to approximately eighty-five per cent, as based on the reduction of biochemical oxygen demand, suspended solids and bacteria.

During the past ten years it has been demonstrated that the average efficiency of the activated-sludge process lies between that of trickling filters and intermittent sand filters. The colloidal solids retained in the trickling-filter effluent, even though it be settled, are largely removed in the activated-sludge process, so that the effluent is generally clearer than a trickling-filter effluent. On the other hand, if the activated sludge suddenly "bulks" or loses its flocculent condition by some unforeseen biological catastrophe, comparatively large amounts of suspended solids may be discharged with the effluent for short periods. All operators of activated-sludge plants are familiar with these intermittent losses of solids, with consequent loss in efficiency. Notwithstanding these temporary lapses the activated-sludge effluent is appreciably superior to the trickling-filter effluent. The superiority is probably most marked in the reduction of bacteria.

For small-scale plants it is possible to pass a trickling-filter or activated-sludge effluent through a sand filter, as at Mt. Kisco, New York, or the Grand Canyon, Arizona, but this additional step is hardly feasible for large plants.

We must, therefore, conclude that the activated-sludge process represents the ultimate degree of complete treatment, on a large scale, at the present time. The additional effect of chlorination on the stabilization of organic matter appears to be appreciable, but hardly sufficient to account for a substantial increase in the percentage efficiency of the activated-sludge process. With regard to bacterial removal, however, chlorination of activated-sludge effluents results in a highly efficient overall reduction, certainly more than ninety-five per cent. When solids escape with the effluent the bacterial efficiency will be lower.

The possibilities of closer approach, in the future, to one hundred per cent treatment on a large scale would seem to depend on the development of more efficient final settling tanks, on more accurate knowledge of how to prevent or control bulking and losses of sludge, and possibly on the development of cheap processes of chemical treatment, either by means of chlorine or other chemicals.

The Specialist

The vocation of sewage works operator is not one to be envied by the thoughtless layman, but there are those who love it. One of the most sympathetic interpreters of the operator's hard lot is Mr. Cohn of Schenectady, who covered himself with literary acclaim (and Imhoff sludge) by his entertaining article in the engineering press last year, in which he described his descent into the more intimate depths of the Schenectady Imhoff tanks. Now Mr. Cohn adds lustre to his literary record by his article in this issue on sewage works odors and their control.

The elusive problem of odor control has been studied by force of necessity at the Schenectady treatment works. In fact, even though undetectable by the olfactory senses, the odors still were there, for, as Mr. Cohn so aptly expresses it, "an odor is an odor even if there is no nose to smell it." But the problem is greatly mitigated by the services of a conscientious tank attendant. As quoted by Mr. Cohn, "To me, the tank attendant who knows how to keep his units in scrupulously clean condition is an artist." A sewage tank artist might seem somewhat incongruous to some of us, but we must all admit that he should be a specialist. And speaking of specialists, how like Chick Sale's famous character, Lem Putt, in "The Specialist," one of the best sellers on the news stands. How much more entertaining could Mr. Cohn be in a saga of the Imhoff tank attendant, who has far greater scope for his talents than the limited field of Mr. Sale's specialist. Instead of a mere two- or eight-holer, the Imhoff tank attendant's field of endeavor may cover acres; the depths so ably explored by Mr. Cohn are far greater than those

depths explored in Mr. Sale's narrative; in short, a tank specialist has a far more complex and extensive field than a mere privy specialist.

But the rewards are likewise greater for the successful tank attendant. "The results of victory are glory enough for the most successful." And as the plant superintendent wends his weary way homeward in the twilight during "the trying hours of early evening," he has the satisfaction of knowing that his tanks are in tender hands, that he has a man "who knows that water under pressure applied just above the surface of the sewage line will prevent the formation of that gelatinous growth with the persistent odor that cannot be washed off the hands." Secure in the knowledge that a specialist is attending his tanks, the harassed superintendent can sleep peacefully.

If Mr. Sale can produce a best-seller in "The Specialist" we are convinced that Mr. Cohn should be able to turn out an even more entertaining story. Aside from this facetiousness there is a great deal of practical, useful information in Mr. Cohn's article. The work at Schenectady on pre-chlorination has been of great interest, and there are many valuable suggestions in Mr. Cohn's article with regard to the prevention of sewage works odors. It is unusual to find such utilitarian purposes combined with a unique, entertaining literary style. Why not have a little levity sometimes in our otherwise instructive but serious technical articles?

Growth of the Federation

On the following four pages will be found a list of the officers of the local associations who are now members of the Federation. There are fourteen associations listed, but some of these, such as the New England and Central States Associations, consist of several states. The New England group includes Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut; the Central States group includes Illinois, Indiana and Wisconsin. The total number of states now in the Federation is therefore twenty-one.

The growth of the Federation in the past year has been remarkable. The principal reason for this growth is that the local association has much to gain by such affiliation, and nothing to lose. The nominal dues are not burdensome to anyone in sewage work who wants to keep abreast of the times. The operators in all states need the helpful advice and suggestions in the papers prepared by our contributors, who are not paid for their work, but who prepare and present their papers for the good the cause.

When the few remaining associations not now members of the Federation have had opportunity to consider all the pros and cons, we do not see any valid reason why they should not apply for membership.

Proceedings of Local Associations

OFFICERS OF LOCAL ASSOCIATIONS, MEMBERS OF FEDERATION

Arizona Sewage Works Association

Officers

President: Dr. F. T. Fahlen, Phoenix.
Secretary-Treasurer: Jane H. Rider, Tucson.
Representatives, Board of Control: George T. Grove, Tucson; Jane H. Rider, Tucson.

California Sewage Works Association

Officers

President: Leon B. Reynolds, Palo Alto.
First Vice-President: F. A. Batty, Los Angeles.
Second Vice-President: B. J. Pardee, Visalia.
Secretary-Treasurer: E. A. Reinke, Berkeley.
Directors: F. M. Lockwood, San Diego, one-year term. A. W. Wyman, Pasadena, two-year term. Philip Schuyler, San Francisco, three-year term. A. K. Warren, Los Angeles, four-year term. C. G. Gillespie, Berkeley, five-year term.
Representatives, Board of Control: G. L. Davenport, Los Angeles; W. T. Knowlton, Los Angeles.

Central States Sewage Works Association

Officers

President: Lewis S. Finch, Indianapolis, Ind.
First Vice-President: F. W. Mohlman, Chicago, Ill.
Second Vice-President: L. F. Warrick, Madison, Wis.
Secretary: Gus H. Radebaugh, Urbana, Ill.
Treasurer: C. K. Calvert, Indianapolis, Ind.
Representatives, Board of Control: Lewis Finch, Indianapolis, Indiana; L. F. Warrick, Madison, Wisconsin.

Iowa Conference on Sewage Treatment

Officers

President: C. H. Currie, Webster City.
Vice-President: Jack J. Hinman, Jr., Iowa City.

Secretary-Treasurer: Lindon J. Murphy, Ames.

Representatives, Board of Control: Max Levine, Ames; Jack J. Hinman, Jr., Iowa City.

Kansas Water Works Association

Officers

President: W. R. Tasker, Herington.

Vice-Presidents: L. B. Mangun, Kansas City; J. C. Gordon, Independence; P. G. McCray, Osage City; L. C. Angevine, McPherson.

Secretary-Treasurer: Earnest Boyce, Lawrence.

Editor: James L. Barron, Lawrence.

Maryland Water and Sewerage Association

Officers

President: Carl A. Hechmer, Hyattsville.

First Vice-President: J. G. Patrick, Luke.

Second Vice-President: S. T. Powell, 213 St. Paul St., Baltimore.

Secretary: F. W. Caspari, 2411 N. Charles St., Baltimore.

Treasurer: Ed. S. Hopkins, Montebello Filters, Baltimore.

Representatives, Board of Control: F. H. Dryden, Salisbury; Abel Wolman, Baltimore.

Missouri Water and Sewage Conference

Officers

Chairman: C. E. Heflin, Cameron.

Vice-Chairman: S. J. Duncan, Moberly.

Secretary-Treasurer: H. D. Peters, Jefferson City.

Executive Committee: W. V. Wier, University City; E. E. Wolfe, Hannibal; W. P. Britain, West Plains; J. N. Wells, Joplin.

New England Sewage Works Association

Officers

President: Stuart E. Coburn, Boston, Mass.

Vice-Presidents: J. W. Bugbee, Providence, R. I.; Warren J. Scott, Hartford, Conn.

Treasurer: Roscoe H. Suttie, New Haven, Conn.

Secretary: F. W. Gilcreas, Boston, Mass.

Representatives, Board of Control: Stephen De M. Gage, Providence, R. I.; Gordon M. Fair, Cambridge, Mass.

New Jersey Sewage Conference

Officers

Chairman: Willem Rudolfs, New Brunswick.

Vice-Chairman: John R. Downes, Bound Brook.

Secretary: Richard C. Smith, New Brunswick.

Representatives, Board of Control: Willem Rudolfs, New Brunswick; Richard C. Smith, New Brunswick.

New York State Sewage Works Association

Officers

President: Kenneth Allen, New York City.

Vice-President: C. A. Holmquist, Albany.

Secretary-Treasurer: E. S. Bedell, Albany.

Executive Committee: One year term—Kenneth Allen, R. H. Gould, R. Suter. Two year term—H. B. Cleveland, M. M. Cohn, Glenn D. Holmes. Three year term—Earl Devendorf, C. A. Holmquist, John F. Skinner.

Representatives, Board of Control: One year term—Kenneth Allen, New York City. Two year term—C. A. Holmquist, Albany.

North Carolina Conference on Water Purification and Sewage Treatment

Officers

President: McKean Maffitt, Wilmington.

Vice-President: P. J. Dishner, High Point.

Secretary-Treasurer: H. G. Baity, Chapel Hill.

Editor: E. G. McConnell, Charlotte.

Executive Committee: H. G. Baity, J. O. Craig, P. J. Dishner, C. G. Logan, McKean Maffitt, E. G. McConnell, H. E. Miller, W. E. Vest.

Publication Committee: E. G. McConnell, W. E. Vest.

Sewage Works Financing: H. E. Miller, Wm. M. Piatt, C. W. Smedberg.

Representatives, Board of Control: H. E. Miller, Raleigh; Wm. M. Piatt, Durham.

Oklahoma Water and Sewage Conference

Officers

President: C. K. Bullen, Stillwater.

Vice-President: Fred Cowell, Lawton.

Secretary: H. J. Darcey, Oklahoma City.

Pennsylvania Sewage Works Association

Officers

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Pennsylvania Sewage Works Association Third Annual Conference

Harrisburg, Pennsylvania

July 16–19, 1929

The Third Annual Conference of the Pennsylvania Sewage Works Association was held at Harrisburg, in the South Office Building, State Capitol, from July 16 to 19, 1929, with 100 in attendance.

The papers presented dealt with questions of a practical nature, and the round-table discussion following the dinner was most interesting and entertaining.

The newly elected officers are: *President,* L. E. Burnside; *First Vice-President,* H. M. Beaumont; *Second Vice-President,* Lowell W. Monroe; *Secretary-Treasurer,* R. O'Donnell.

The meeting of the Sewage Works Association was followed on the next two days by that of the Pennsylvania Water Works Operators' Association. While these two associations are entirely distinct, yet up to and including this time they have been held at the same place, the one following the other. An amendment to the constitution of each organization was passed with the idea of carrying out this scheme in the future, since there is a considerable overlapping of members who desire to attend both meetings.

The new list of officers of the Water Works Operators' Association is as follows: *President,* C. F. Drake; *First Vice-President,* J. W. Dunwoody; *Second Vice-President,* C. L. Farson; *Secretary-Treasurer,* I. M. Glace.

Dr. Theodore B. Appel, Secretary of Health, Harrisburg, welcomed the members of the Sewage Works Association on Tuesday morning and those of the Water Works Operators' Association on Thursday morning.

At the morning session of the Sewage Works Association, W. L. Stevenson, Chief Engineer, Pennsylvania Department of Health, presented a paper on the "Policy of the Sanitary Water Board for Improvement of the Streams;" Dr. W. A. Taylor, Vice-President, LaMotte Chemical Products Company, Baltimore discussed "Determining pH of Sewage by the Dilution Method."

The following papers were presented at the afternoon session: "Studies on Sludge Treatment," by Michael J. Blew, Research Engineer, Bureau of Engineering, Department of Public Works, Philadelphia; "Gas Collection from Imhoff Tanks," by Wellington Donaldson, Fuller and McClintock, New York; "Odor Control at Sewage Works," by Morris M. Cohn, Sanitary and Testing Engineer, Department of Public Works, Schenectady. These were followed by movies and later by a dinner and round-table discussion at the Colonial Country Club.

The morning session on Wednesday was opened by Francis S. Friel, Albright and Mebus, Philadelphia, who gave a paper on the "Design and Operating Features of Sewage Treatment Works near Habitations, Particularly at Whitemarsh Valley Country Club and Wawa Dairy Farms," which was followed by "Recent Maryland Studies in Sewage and Trade Wastes Treatment" by Abel Wolman, Chief Engineer, Maryland Department of Health, Baltimore; "Description of Hershey Sewage Treatment Works," by H. N. Herr, Chief Civil Engineer, Hershey, Pa.; and "Description of Lebanon Sewage Treatment Works" by Dr. George L. Holstein, Superintendent Parks and Public Property, Lebanon. The afternoon was devoted to sewage plant inspection at Hershey and Lebanon.

New York State Sewage Works Association First Annual Conference

Rochester, New York

July 27, 1929

Forty sanitary engineers, chemists and operators connected with sewage disposal works met July 27, 1929, at the Hotel Seneca, in Rochester, for the first conference of the New York State Sewage Works Association, notice of which was published in the July issue of THIS JOURNAL. There were forty-five representatives from cities throughout New York State, including employees of the New York State Department of Health and visitors from Brazil, California, Oklahoma, Canada and New England.

Following a brief business meeting, Kenneth Allen, President of the Association, gave a short paper on the history of the art of sewage disposal and the aims of the Association. Professor L. B. Reynolds, President

of the California Sewage Works Association, and Mr. S. E. Coburn, President of the New England Association, described the work of their associations. Harold W. Baker, Commissioner of Public Works in Rochester, gave a splendid paper on the "Collection and Disposal of Municipal Wastes in Rochester," illustrated by a remarkable film on the subject prepared by the city. Mr. Coburn read a paper on "Sludge Digestion" telling in humorous allegory the part that bacteria play in sewage disposal and W. A. Ryan, chemist of the Rochester sewage treatment plants, read a paper on "Simple Laboratory Control for Small Sewage Disposal Plants" and gave a demonstration of the use of the necessary apparatus and reagents.

At the noon luncheon Vice-Mayor Adler welcomed the group and gave a brief address on the Rochester plan of city government. J. F. Skinner described briefly the three sewage treatment plants of the city and distributed to each member specially prepared reports which included descriptions and photographs of the plants, operating data and outline plans of the works. Following the luncheon an inspection trip by chartered bus was made to the three plants.

The Executive Committee met in the evening and appointed several standing committees, discussed many matters of business and decided that the next meeting would be held on October 19, 1929 in Schenectady. Morris Cohn, chairman of the Program Committee, has outlined an interesting program, and further information concerning it will be published in the next issue of THIS JOURNAL.

Although this Association was organized less than three months ago, it already has a membership of 167, and hopes to pass the 200 mark before the Fall Meeting.

California Sewage Works Association
Second Annual Meeting

Oakland, California

October 7–10, 1929

The Second Annual Meeting of the California Sewage Works Association was held at the Hotel Oakland on October 7–10, 1929.

The meeting opened very informally Monday, October 7th. The day was spent in visiting the sewage treatment plants at Carmel, San Juan, Gilroy, Santa Cruz and Montezuma. A barbecue lunch was held at the Gilroy Golf Club at which time the visitors were guests of the Dorr Company.

The formal opening of the meeting was held Tuesday, October 8th, when

William H. Parker, Commissioner of Streets, Oakland, gave the address of welcome. Leon B. Reynolds, President of the Association, responded. This was followed by a business meeting, discussion of the plants visited on Monday, and a paper by F. A. Batty on "Oil Exclusion and Removal." At the noon luncheon the members were guests of the American Concrete Pipe Company at its Oakland plant and this was followed by an inspection of the Hume centrifugal process of concrete pipe manufacture.

Tuesday afternoon a symposium was held on "Sewage Disposal and Costs" with the presentation of the following papers:

"Digestion of Activated Sludge at Pomona," F. H. Froehde, City Engineer.

"Separate Industrial Sewers and Chlorination at Tulare," R. M. Berryhill, City Manager.

"Foaming and High-Rate Land Disposal at Visalia," L. H. Gadsby, City Engineer.

"Pumping and Foaming at Stockton," W. B. Hogan, City Manager.

"Gas Burning and Chlorination at San Bernardino," F. S. Currie, Consulting Engineer.

"Cost Keeping System of the Los Angeles County Sanitation Districts," A. K. Warren, Chief Engineer.

"Fly Control at Sewage Treatment Plants," W. B. Herms, Prof. of Entomology, University of California.

Discussion of the last-named paper was presented by Hilliard Hall, Grand Canyon, Arizona; R. F. Goudey, State Dept. of Public Health, Los Angeles; representatives of Los Angeles County Sanitation Districts; and A. M. Jensen, Commissioner of Public Works, Fresno.

On Wednesday the following papers were read:

"Sewer Grades," A. M. Rawn, Sanitation Districts, Los Angeles County.

"Relative Costs of Sewerage," D. E. Perry, Manager and Assessor, Marin Sanitation District of San Anselmo.

"State Supervision of Sewage Disposal," C. G. Gillespie, Chief, Bureau of Sanitary Engineering.

"Responsibilities and Procedures of Municipalities," B. J. Pardee, City Manager, Visalia.

A symposium was held in the afternoon in coöperation with the engineers' section of the League of California Municipalities on "Sewage Disposal to Salt Water." The following papers were presented:

"Float Surveys and Wrought-Iron Outfalls at Santa Cruz," C. G. Hyde, Prof. of Sanitary Engineering, University of California.

"Concrete Outfall, B. Coli Surveys at Los Angeles," W. T. Knowlton, City Sanitary Engineer.

"Settling Tanks for Bay Outlets at San Diego," F. M. Lockwood, City Manager.

"Slough Disposal at San Anselmo," C. C. Kennedy, Consulting Engineer, San Francisco.

"Experimental Work on Outlet Structures for Los Angeles County," A. M. Rawn, Asst. Chief Engineer, Los Angeles County.

"Bay Disposal and Chlorination at Newport Beach," R. L. Patterson, City Engineer.

"Concrete Pipe and Pumping at San Rafael," H. K. Brainard, City Engineer.

"Sewage Disposal in California," L. B. Reynolds, Stanford University.

At the noon luncheon on Wednesday the members were guests of N. Clark & Sons, clay products manufacturers, and an inspection of the manufacture of vitrified clay pipe followed.

On Wednesday evening an industrial exposition and dance was held in conjunction with the League of California Municipalities.

Notice of the Missouri Water and Sewerage Conference Fifth Annual Meeting

Chillicothe, Mo.

October 21–23, 1929

The Fifth Annual Meeting of the Missouri Water and Sewerage Conference will be held in Chillicothe, Missouri, October 21, 22 and 23, 1929.

The program will deal with papers particularly of interest to water and sewage works superintendents.

A special innovation will be that of a joint meeting with the Missouri Association of Municipal Utilities.

Notice of the North Carolina Sewage Works Association Seventh Annual Meeting

High Point, N. C.

November 4–6, 1929

The Seventh Annual Meeting of the North Carolina Sewage Works Association and the Ninth Annual Convention of the North Carolina Section, American Water Works Association will be held jointly at the Sheraton Hotel, High Point, N. C., November 4, 5 and 6, 1929.

Reviews and Abstracts

H. W. STREETER

The Emscher Clarification Plant at Essen-Karnap

By M. Prüss

Pamphlet 52 pp., 41 figures. *Gesundheits-Ingenieur* (Sept., 1929)

Abstracted by J. K. Hoskins

In January, 1929, a new clarification plant of the Emscher District was placed in operation, in which is provided a two-hour retention period for the entire flow of the Emscher previous to its discharge to the Rhine for the purpose of removal of the coarse suspended matter. The plant is designed to treat an average daily flow of 850,000 cu. meters and will retain 250,000 tons of sludge annually with about 50 per cent water content. The design and construction of the plant are described and illustrated in this publication.

The whole Emscher watershed has a population of about 2,500,000 and contains 200 mines which produce annually 80 to 90 million tons of coal. Ordinarily the combined domestic and trades wastes are diluted 3.5 times their volume in the Emscher; the further dilution afforded by the Rhine is at all times so great (140 to 1 in dry weather to 44 to 1 during high water) that removal only of settleable material from the Emscher affords ample purification. The completion of the industrial development of the area has made practicable a central treatment plant for the combined wastes, a project not practicable heretofore.

In spite of vigorous efforts to reduce the suspended matter contributed by mines and blast furnaces, the settleable solids of the Emscher remains normally at about 2.5 cc. per liter after 2 hours' standing, and at times of high industrial activity may be even doubled. To this is added the ammonia wastes from about 100 coke plants, totaling about 250 liters per second and containing 10,000 tons of phenol annually. This discharge to the Rhine has resulted in eliminating fish on the right side of the stream and rendering all edible fish in the lower river unfit for use even in Holland. The removal of phenol pollution, therefore, became imperative. Accordingly, after extensive study it was found possible to recover about 80 per cent of the phenols from the gas wastes by washing with benzol, the by-products obtained paying the full cost of treatment. At present the waste phenols discharged have been reduced to 50 per cent

of their former volume and when installations are completed will be reduced still further.

For the retention of the insoluble materials from coal and coke production, various sedimentation plants on several tributaries of the Emscher were previously constructed. Increasing quantities of these materials necessitated the provision for sedimentation of the entire river flows. Extensive research demonstrated that this sediment, if dried, was of value as a powdered fuel. The design and construction of a central plant and diversion works to effect this result, approved in March, 1927, are discussed in detail.

The four sedimentation basins provide for a normal two-hour retention period of an average flow of 10 cu. meters per second. Each basin is 50 m. wide and 160 m. long and 3.5 m. deep, with provision for a clear water depth of 2 m. and sludge depth of 1.5 m. Sludge drying beds surround the basins on three sides to which the sediment is pumped, and in which the water content will be reduced to about 50 per cent. This material is to be further dried in cylindrical rotary kilns to 1.5 per cent moisture content, in which condition it is available as fuel.

Sewage Impurities and Purification Effect of Sedimentation Processes

BY M. PRÜSS

Gesundheits-Ingenieur, **16**, 270 (April 20, 1929)

ABSTRACTED BY J. K. HOSKINS

The author suggests a method for representing graphically the different physical conditions of the impurities in sewage and the improvements that are effected by various treatment procedures, in such a way as to be understood by non-technical persons such as municipal officials and commissions who must deal with the management of sewage disposal problems. The scheme is based on the per capita daily contribution of 150 g. of foreign material, 75 g. of which is insoluble. Of this latter, $^2/_3$, or 50 g., can be removed by proper mechanical sedimentation, corresponding to a daily sludge content per person of 1 liter with 95 per cent water content. This dry substance is composed of 70 per cent organic and 30 per cent mineral matter. The soluble matter is about $^1/_3$ organic and $^2/_3$ mineral. As this dissolved mineral material places no burden on the receiving stream, it is regarded as foreign matter rather than polluting, hence the total polluting matter amounts to 100 g. per capita daily and the foreign matter to 50 g. A detailed statistical table gives the

composition of the waste material in terms of per cents of the whole, based on per capita contribution.

Sewage Disposal Practice in Europe

BY CHAS. GILMAN HYDE

Western Constr. News, **4**, No. 13, 345–52 (July 10, 1929)

ABSTRACTED BY C. T. CARNAHAN

This article is the result of an extensive inspection trip of 23 sewage treatment plants serving 20 communities in Great Britain and the Ruhr district of Germany, carried out by Prof. Hyde in 1928.

Rivers and River Control.—The effectiveness of river control constituted one of the most striking observations of the trip.

In Great Britain stream control is regulated by the Ministry of Health and by conservancy boards charged with redeeming or conserving the quality of the inland waterways. The control of the Thames in England and the Ruhr in Germany are outstanding.

Types of Sewerage Systems and Types and Condition of Sewage.—Practically all European systems are of the combined type, handling both sewage and storm water. A few exceptions were found in the cities of Oxford, Cheltenham and Reading where separate sewers exist.

The treatment plants handle relatively large volumes of flow during wet weather. Usually three times the dry weather flow is treated the same as the dry weather flow; three to six times the dry weather flow is partially treated, generally by sedimentation; over six times the dry weather flow is discharged directly into the stream as it is considered too dilute to cause trouble. This general rule is varied from place to place as conditions warrant.

The sewage from industrial towns contains trade wastes varying from 20 per cent to 50 per cent of the normal dry weather flow.

Wool-scouring, gas-house, acid-iron, tannery, dye and brewery wastes cause considerable trouble. Sewage from residential communities is easier to treat, but is much stronger than that from similar American towns, due to the greater per capita water consumption in America.

Treatment Sites.—In England large tracts of land are usually set aside for treatment works, and many of the plants are beautifully landscaped. In Germany and other continental countries, less generous areas are set aside and the treatment works are usually constructed in industrial areas.

The Use of Screens.—Bar screens or their equivalent are found in

nearly all plants. In the large British plants screens are supplied with automatic rakes. Rotary screens are popular in Germany but are not often found in Great Britain.

The Use of Grit Chambers and Detritus Tanks.—All works treating combined sewage provide grit chambers, detritus tanks or both, to handle the sand and grit. Many tanks are well designed and hold the coarse mineral matter. The grit removal problem is troublesome, especially in the smaller plants. Grit removal in the larger plants is accomplished mechanically, bucket elevators or clam-shell dredges being used.

The Use of Oil Catchers.—Mineral oil, flushed from the streets, is particularly troublesome in activated sludge plants as it reduces the aeration efficiency. Much of the oil can be arrested and skimmed off in works with large pretreatment tanks. A very successful device has been perfected at the Essen-Rellinghausen plant in the Ruhr, and some such device will probably come into general use for oil removal.

The Use of Plain Subsidence in One-Story Tanks.—Plain subsidence is most commonly used for the removal of settleable solids. Sometimes this is the only process, but more usually it is preparatory to further treatment, especially where the activated sludge process is used. In Great Britain plain subsidence is generally used for the treatment of excess storm flows, either alone or as pretreatment before sand beds, or with broad irrigation. Both horizontal and vertical flow tanks are used in Great Britain with no great preference for either type as above the other.

The Use of Coagulants.—Coagulants are used in a large number of British works. At Bradford, sulphuric acid is employed in the recovery of large amounts of salable greases from wool-scouring wastes. At Leeds, alum is used on account of the character of the trade wastes treated. At Glasgow, lime and alum is used for coagulation.

The Use of One-Story Septic Tanks.—Only three of the British works visited employed septic tanks, which have been abandoned at the larger works in Great Britain. They never seem to have been popular in Germany, where every effort is made to keep the sewage as fresh as possible. They are used for small works, isolated houses and institutions as in the United States.

The Use of Imhoff Tanks.—Only one of the British plants visited was equipped with Imhoff tanks. They are very popular in Germany, and are much used as pretreatment prior to final treatment by other means.

The Use of Contact Beds, Trickling Filters and Intermittent Sand Filters.—Contact beds, much used in Great Britain 15 or 20 years ago, have been abandoned in all but three of the plants visited. At one plant, Bury, the old beds were converted into trickling filters, and this might be done with some of the present beds.

Trickling filters are extensively used in England for final treatment. Mechanical distributors are favored over fixed spray nozzles. Depths and materials are similar to those used in America. In the Ruhr only one out of 45 plants used trickling filters.

Intermittent sand beds are not used except in a few cases to handle excess storm flows.

The Use of the Activated Sludge Process.—Activated sludge plants are being used extensively in Great Britain and Germany. In half of the British works visited, activated sludge plants were in operation, mostly as a means of relief for the existing works which had become overtaxed. In some cases large scale plants were being operated as an experiment. The most efficient plant was at Essen-Rellinghausen, using submerged paddles and diffused aeration with pretreatment in Imhoff tanks. Sludge disposal is the greatest problem connected with the activated sludge process, aside from the relatively great cost.

The Use of Submerged Contact Aerators.—The only plants using this type of treatment are those designed by Imhoff and his associates in the Ruhr. Experiments show this method to be efficient and economical for partial treatment. There were 10 plants in the Ruhr utilizing this treatment in 1928.

The Use of Broad Irrigation.—This process is in use in a number of places, for treatment of both sewage proper and excess storm flows. In general, the sewage receives some sort of pretreatment. The sewage of Berlin, Paris and Milan is used to irrigate crops.

Sludge Treatment and Disposal.—The sludge problem, especially in Great Britain, has not been satisfactorily solved at many plants, particularly at activated sludge plants. Plants on or near the sea barge the sludge to sea. Several plants use separate digestion with subsequent drying or direct disposal to farmers. Drying is usually carried out on open beds. At a large number of plants the crude sludge is disposed of on private or public lands by trenching or by the ridge-and-furrow method. In no case is the sludge dewatered and made into fertilizer as is done at some plants in the United States. Sludge cake is produced at Bradford and Leeds but no market exists for the cake. Experiments are being carried out at Leeds, burning the cake and selling the ash which has a market value of $2.10 a ton.

The Use of Chlorination.—Chlorination of sewage effluents is rarely done in Europe. In the Ruhr some stand-by chlorination plants are kept as an emergency measure. At Bath, chlorination is carried out on a long outfall to prevent odors and decomposition. At one English plant the entire effluent is chlorinated as the effluent is used by manufacturers a short distance below the plant.

The Use of Measuring and Recording Devices.—One of the striking

features of all types and sizes of British works is the extent to which measuring and flow recording devices are used. Every plant visited was able to give complete data on the volumes of sewage and sludge handled.

Other Details.—Rectified channels are used in Germany to convey sewage and to keep it in a fresh condition.

In the large English cities, high-level sewers are constructed, wherever possible, to avoid pumping sewage.

Experimental plants are set up and operated to a great extent in Europe, and no actual design of a plant seems to be undertaken without first experimenting on a practical scale.

Sludge Filter Design and Operation

BY H. C. SHENTON

The Canadian Engineer, **56**, 571–3 (June 4, 1929)

ABSTRACTED BY C. T. WRIGHT

Practice varies greatly with regard to the construction and working of sludge filters, owing to the great difference in the quality and quantity of sludge produced with the various methods of sewage treatment.

Sludge filters are used for dewatering crude fresh sludge, sludge which has become septic or sludge which has received chemical treatment. It also may have been partially digested or completely digested. The sludge may have been affected by trade wastes which may increase its bulk or render the task of dewatering more difficult. The filtration or dewatering of activated sludge is a problem in itself and this may be subdivided in relation to the sludge obtained by full or by partial treatment or to the sludge obtained from different types of activated sludge processes.

Object of Filtration.—In most modern works the liquid effluent from a sludge filter is returned to the settling tanks so that thorough filtration is unnecessary. The important point is to determine the depth and grade of filtering material which will intercept the solid matter without the filter becoming clogged. Provided the filter does not clog, it may be advisable and economical to allow a fairly concentrated effluent to escape, in order to allow the sludge to become dewatered more rapidly.

A sludge filter needs underdrainage as efficient as that of a sewage filter and the need of keeping the filter clear of obstruction is as great in one case as in the other.

The advantage of covering sludge beds is obvious, thus saving filter area and labor, and leading to definite results.

Area of Sludge Filters.—The idea prevails that the rule of the Ministry of Health is one square yard of filter area for every seven persons. It is very improbable, however, that the Ministry have any fixed rule, for they undoubtedly prefer to consider each case on its merits.

The opinions of other authorities regarding the area of sludge filters may be briefly listed as follows:

Folwell, in the latest edition of "Sewerage," just published, gives the following allowances: Filters for septic-tank sludge treatment, 1 sq. yd. for from 4½ to 9 persons; digested sludge, 1 sq. yd. for from 6 to 11 persons. If the digested sludge is heated, the filter area should be reduced from 25 to 50 per cent and where filter beds are provided with a glass roof the filter area may be reduced 30 to 50 per cent. Fuller gives an allowance of 26 persons per sq. yd. for digested sludge.

In the recent report of the Manchester deputation dealing with sewage disposal works in Germany, the area of sludge beds dealing with digested sludge at Stuttgart, population 350,000, is given as 1 sq. yd. for every 27 persons, while at Munich, population 400,000, 1 sq. yd. for every 33 persons.

The latest edition of "Sewerage and Sewage Treatment" by H. E. Babbit on American practice gives an allowance of 1 sq. yd. for from 1 to 9 persons.

Dr. Imhoff's allowance for digested sludge is 1 sq. yd. for 8 or 9 persons, for plain sludge from sedimentation tanks, 1½ persons per sq. yd.

It would be very unwise, however, to draw conclusions from these figures without close investigation. The differences are very remarkable and suggest that closer attention should be given to the subject.

Innovations in the Treatment of Leipzig Sewage

BY FR. MIEDER

Gesundheits-Ingenieur, **20–22**, 1–15 (1929)

ABSTRACTED BY S. L. NEAVE

Until 1923, the main treatment plant at Rosental, consisted of 12 tanks for chemical coagulation, but the introduction of chlorination and increasing load necessitated, by 1926, the construction of another unit, embodying some unusual features. The unit consists of 4 rectangular sedimentation basins, 50–60 m. long, 10 m. wide and 2 m. mean depth, the bottom having a slope of 1 in 75 toward two inverted pyramidal sludge-hoppers at the inlet end of each tank; steel rails on the tank walls support a moving superstructure carrying a single, rubber-edged scraper, the width of the tank, which drags the deposited solids into the hoppers.

The latter hold two-days' accumulation, and empty by hydrostatic pressure. The one scraper serves all tanks, and requires about 2 H. P. for $^1/_2$ hour per tank; a daily forward trip of the scraper keeps the tank sides and bottom clean, while on the backward trip the elevated scraper skims off the floating solids behind the overflow baffle; by separating this grease-containing scum from the settled solids, the latter undergo more rapid and complete (separate) digestion, avoiding scum formation which interferes with gas-collection and a resultant greasy loam unsuited to agricultural needs.

For chlorinating the settled sewage before discharge into the river Elster, two special saturators are used, each having a capacity of 120 kg. Cl per hour, which introduce liquid chlorine directly into a high-pressure water main and thence to the plant; the extensive and costly equipment for dissolving the requisite amount of gaseous Cl is thus avoided. Leipzig sewage requires 10–50 gm. Cl per cu. m., and satisfactory bacterial removal is insured by 0.3 mg./l. of residual Cl after 10 minutes. Surveys of the river showed average total counts (per cc.) of 5500 above the city; 48,000 below the city without chlorination, and 1200 with chlorination.

In anticipation of the future removal of the plant farther downstream giving opportunity for changes in design, studies in the activated sludge process were instituted in 1925. For preliminary sedimentation, two 5-m. Emscher tanks were modified to give $1^1/_2$-hour sedimentation periods and, on the basis of 150 l. of sewage per capita, a lower sludge compartment storage of 30 l. per capita for settled solids plus an additional 30 for digesting the excess activated sludge; the gas vents were covered for gas-collection. Two rectangular tanks, each 20 m. long, 2 m. wide and 2 m. effective depth, and each having 0.26 sq. m. of $^{40}/_{120}$ double-porous filter plates arranged along one side of the tank bottom, provided the aeration; one contained a submerged paddle-wheel (Rellinghausen system) for comparison of stirring plus aeration with aeration alone. Preceding the tanks is a grease-catcher (air flotation), and following them a sedimentation tank and a fish-pond provided with filtros aerators. On account of septicity resulting during preliminary sedimentation, the assumed 6 to 6 $^1/_2$-hour aeration period had to be increased to 8 to 10 or even 11 in cold weather; without the paddle-wheel, 10 vols. of air were required per volume of sewage, while with the wheel, 7 vols. sufficed. Inexplicable spells of bad performance were encountered, perhaps due to variations in sewage strength or occasional industrial wastes, but prechlorination of the Emscher influent or its dilution with water showed no improvement. Excluding such spells, the analytical data show:

	Influent		Effluent	
	Range	Ave.	Range	Ave.
Permanganate utilization, mg./l. $KMnO_4$	120–300	220	60–120	95
Methylene-blue stability (37°).....	1/2–2 h.	1 h.	1–10+ d.	4 d.

Hydrogen sulphide, mg./l. H_2S.....	0.3–1.5	0.8	0–trace	0
Ammonia, mg./l. NH_3.....	30–70	50	30–50	40
Nitrate + nitrite, mg./l. $N_2O_3 + N_2O_5$...	0-trace	0	0–1.0	0.3
Oxygen, mg./l. O_2.....	.....	Trace	0.5–6.0	3.0
B. O. D., 5-day.....	.....	220	.....	30.0
pH.....	6.8–7.8	7.6	7.2–7.8	7.5

Laboratory experiments with a "Tauchkörper" of lath-racks showed abundant growth of fungus which necessitated cleaning the racks every 10 days, and permanganate-utilization removals of 8.3–42.5 per cent depending upon the elapsed time since cleaning the racks; the mean reduction was 235 to 187 mg./l. or 20.5 per cent, while the activated sludge process showed 62.5 per cent during this 12-day period. These favorable results are to be confirmed by tank studies.

Other problems included in the experimental program are pre-aeration of returned sludge, comparison of submerged and half-submerged paddle-wheels, and separate sludge digestion in a heated tank.

Sewage from the suburb Möckern is pumped to the main treatment plant at Rosental, while that from Wahren enters the river largely without treatment. Increasing population load made desirable a separate treatment plant for these districts. This plant, shortly to be put into operation, consists of 2 Emscher tanks followed by 3 activated sludge and 2 "Tauchkörper" tanks, operating in parallel, all designed for a tributary population of 18,000.

Modification of settling-tanks, and enlargement of the sprinkling filters, for the suburb Leutzsch are described, together with a projected grit-chamber for the Rosental plant to consist of two Dorr detritors.

The Utilization of Digestion Gases in Halle

BY DR. ING. HEILMAN AND DIPL. ING. KARCHER

Gesundheits-Ingenieur, **52**, 571 (1929)

ABSTRACTED BY G. P. EDWARDS

The equipment for sewage treatment at Halle consists of coarse screens, grit chambers and Imhoff tanks. The Imhoff tanks are arranged so that there are eight settling tanks supplying twenty-four digestion tanks.

In 1926, one series of tanks was provided with an experimental gas collection apparatus which proved quite successful. In the summer of 1927, the whole clarification plant was fitted for gas collection. Concrete covers were made absolutely gas tight with a heavy coating of asphalt. A space was left in the concrete covers for installation of the gas collection apparatus. This apparatus consists of a cup containing water to a depth of

about 35 centimeters into which the gas dome dips. A porous wooden plate wedged tight against the foot of the cup prevents the sludge from rising with the gas collector. The gas dome is kept fixed by means of strong iron bracings. Gas is removed at the highest point in the dome.

Gas collectors from any section of the tanks may be shut off by valves without disturbing the gas operation of the other tanks. These valves may also be used for the collection of gas samples, drawing off scum and thawing of the pipes during very cold weather. Each group of three tanks is connected through a common pipe which joins one of two main underground collecting pipes running along two sides of the treatment plant. These two main pipes unite before entering the gas purifiers and compressors.

Gas samples are collected regularly from the collection pipe. The methane content varied from 63.9 to 77.3 per cent. The average composition is 72.91% CH_4, 24.56% CO_2, 1.59% N_2, 0.63% O_2.

Generally the H_2S content is very small and varies between 0.076 and 0.58 per cent. From the observations made, there seems to be more H_2S in summer than in winter.

The H_2S content has an injurious effect on parts of the gas motor. The pistons and cylinder walls of the combustion chamber are particularly damaged by the H_2S, even though an attempt is made to remove it by treatment in two tanks containing bog iron ore. These two tanks are so connected that the gas can be forced through one and then the other or through either one independently. The gas used for the motor power and heating of the machine houses is purified. A known constant pressure is maintained in the suction line to which the motor is attached by a pressure regulator placed in the pipe between the purification apparatus and the motor. A supply of gas is stored in a rubber bag inserted in front of the motor. About twelve cubic meters per hour of purified gas is necessary for the large motor which runs the air compressor supplying the air for the submerged contact aerators. The gas motor for the pumping of sludge requires about six cubic meters per hour.

The hot water plant which heats the old and new machinery houses requires from 2 to 2.5 cu. m. per hour.

The greater part of the gases not necessary for the maintenance of the treatment plant, goes unpurified from the general collection pipe to the low pressure regulator. This is adjusted to a pressure corresponding to 50 mm. of water.

The gas flows from the low pressure regulator through compressors to the gas apparatus. The high pressure regulator is adjusted at 2 atmospheres. If this pressure is exceeded, a valve is opened into the low pressure line.

The apparatus was arranged so that either the gas motor or the reserve

electric motor can be used for operating the compressors. The electric motor is seldom used in the daytime.

The construction of pressure regulators eliminated the necessity of gas containers.

The total cost of this gas collection apparatus amounted to about 125,000 marks and the installation of more than 7 km. of gas pipe cost about 90,000 marks. The treatment plant pays 4 pfg. per cubic meter of gas giving 7500 W. E., and 28.60 marks per ton of coal. The W. E. or coal price varies during an average month so that the gas price varies proportionately.

Since, from our determinations, especially from our experimental plant, we can rely upon a monthly gas yield of 50,000 cubic meters in an average month, we can expect a yearly income from gas of 24,000 marks and a saving of about 2000 marks on the cost of electrical current through the construction of gas motors for sludge pumping. There is about 12 per cent for interest payments and amortization of the cost of the treatment plant.

This year, a secondary digestion tank of 1000 cubic meters capacity was built. This tank was heated with digestion gas. It is estimated that the amount of gas yielded to the gas plant will be materially increased.

The Water and Sewage Group of the German Chemical Society Meeting in Breslau, 1929

Technisches Gemeindeblatt, **32**, 208 (August 5, 1929)

ABSTRACTED BY G. P. EDWARDS

The following papers relating to sewage treatment were presented in the Water and Sewage Section of the German Chemical Society at the 42nd meeting held in Breslau on May 22, 23 and 24, 1929.

Fr. Mieder, Leipzig, and Dr. Hilland, Bitterfeld, "Sewage Treatment Plants in the Large American Cities."

Nearly all the water purification plants inspected on an American tour appeared in a more favorable light than the sewage treatment works. There are some very large sewage treatment works under construction. New developments include mechanically operated grit chambers, specially shaped scrapers, screens and skimming tanks which have a detention period of only 15 minutes. The settling tanks are nearly all Imhoff tanks or shallow Dorr tanks. Irrigation fields and fish ponds are not in use. Many biological sprinkling filters are found. Activated sludge plants, in general, employ compressed air instead of paddles or stirring apparatus. Chlorine is used quite widely for disinfection.

Prof. Ing. Heilmann, Halle, "The Construction of a Secondary Digestion Tank for Sludge and the Possibility of Aiding Sludge Digestion."

The digestion of sewage sludge depends on the condition of the fresh sludge, on the mixing of fresh and digested sludge, on the temperature in the digestion chamber, on the separation of the decomposing bacteria and on the hydrogen-ion concentration, which should be between pH 7.3 and 7.6. The digestion chamber becomes more efficient when the temperature of the sludge is raised. The bubbles of gas are easily expelled by circulation.

Prof. Dr. Czensny, Berlin, Friedrichshagen, "The Detection of Tar and Phenol in Polluted Fishing Streams."

The process worked out by Bach has been improved so that 0.01 mg. per liter phenol can be detected in 250 cc. of water.

Dr. Viehl, Leipzig, "The Chlorination of Sewage."

Based on many experiments, enough chlorine was added to the sewage so that free chlorine was easily detected in the effluent with starch KI and weakly or not at all with *o*-tolidin. The removal of suspended matter was not noticeably affected by chlorination. Prechlorination should be used in Leipzig to remove odors in summer and to save chlorine.

Dr. v. Luck, "Contributions to the Investigations of Sugar Plant Wastes."

The practical methods for investigations of sugar plant wastes are not so numerous as for city sewage. In the investigations at Hildesheim and Magdeburg determinations of chlorine, $KMnO_4$ demand, total nitrogen, ammonia, organic nitrogen, sugar, organic acids, hydrogen sulfide, digestibility, residue on evaporation, loss on ignition, hydrogen-ion concentration, free chlorine and biological oxygen demand were made. Part of these determinations were qualitative and part quantitative.

Dipl. Ing. Meyer, Magdeburg, "The Determination of the Biological Oxygen Demand as a Measure of Purity of Sugar Plant Wastes."

The biological oxygen demand of sugar plant wastes was reduced by fermentation and digestion. The oxygen demand, which depends mainly on the sugar content, acids and the organic nitrogen of the sewage, is a good index of the purification obtained. The total biological oxygen demand can be calculated from the 2-day demand according to a determined formula.

Dr. Pick, Aussig, "Chlorination of Sugar Plant Wastes."

The experimental chlorination of the combined sewage takes place between the preliminary clarification plant and the secondary treatment plant. After an initial addition of 30–50 gr. and a later addition of only 5 gr. chlorine per cubic meter, all the odor disappeared.

These papers will appear in the next year book, "Vom Wasser," Volume 3, probably late in 1929.

Second Annual Report (1928), Metropolitan Drainage Commission of Minneapolis, and St. Paul, Minnesota[1]

BY J. A. CHILDS, CHIEF ENGINEER

ABSTRACTED BY C. C. RUCHHOFT

Report of Metropolitan Drainage Commission (260 pages).—The Metropolitan Drainage Commission was created by the Minnesota Legislature in 1927 and was authorized to study the subject of sewage disposal for the Twin City area. The Twin Cities are located on the Mississippi River about 475 miles from its source in a chain of lakes. The river enters Minneapolis at an elevation of 802 and has a fall of 70 feet near the business center of Minneapolis at St. Anthony Falls, after which there is short swift section. About six miles below St. Anthony Falls there is another drop of 33 feet to an elevation of 690 at the Twin City Lock and Dam. This dam has created a pool of relatively quiet water extending five miles upstream with a capacity of 340,000,000 cubic feet. All of the sewers of Minneapolis, except one, and eleven of those of St. Paul discharge into the river above the dam. Objectionable conditions have become increasingly noticeable above the dam and septic conditions are usually found during the summer when the flow of the river is less than 5000 cubic feet per second.

It was found in 1928 that 3,000,000 cubic yards of sludge and silt have been deposited in this pool. The section of the river below the Twin City Lock and Dam is relatively rapid and tends to prevent sludge deposits. The Federal Government, in the interest of navigation, is constructing a new dam at Hastings which will create a second relatively quiet pool extending about thirty miles up to the Twin City Lock and Dam. It is probable that objectionable conditions will be created by the operation of the Hastings Dam. With a dry-weather flow of 4000 c. f. s. the Twin City Lock and Dam has increased the time of flow from St. Anthony Falls to the dam from three hours to thirty hours. Similarly the flow time will be increased from 35 to 310 hours from the Twin City Dam to the Hastings Dam.

Population estimates for 1927 were made and the trend growth curve of the cities projected to obtain estimates for 1970. A population of 1,450,000 in 1970 was taken as a basis for the design of the intercepting sewers. The combined area of the Twin Cities is 64,108 acres of which 40,764 are sewered. The existing sewerage systems are, with few ex-

[1] *The first part of this report covers investigations of sewage disposal projects with a review of the data and conclusions by Pearse, Greeley and Hansen, Chicago. The second part includes a report of studies of the pollution of the Mississippi River made by the Minnesota State Board of Health in collaboration with the Minnesota Commission of Game and Fish and the Wisconsin State Board of Health.*

ceptions, of the combined type and all of them discharge directly into the Mississippi.

During the winter of 1927 and 1928, weir measurements were made on practically all sewer outlets. The average flow of domestic sewage and industrial wastes was estimated as 167 million gallons per day in 1970, and the ground water as an additional 103 m. g. d. for the two cities in wet weather. Storm water capacity of 243 m. g. d. sufficient to carry the run-off which would result from a rainfall intensity of 0.04 inch per hour, was allowed for the interceptors. Rainfall statistics indicate that the interceptors would overflow about 150 hours per year with this capacity.

Twelve interceptor arrangements were studied, particularly with reference to costs, to determine the most desirable of the several possible plant sites.

A total of 470 composite samples from sixty-one sewer outlets were examined. The examination included 5-day biochemical oxygen demand test, the determination of fixed and volatile suspended matter, the hydrogen-ion concentration and bacteriological examination for total count and *B. coli*. From the biochemical oxygen demand data and sewage-flow measurements the population equivalents of each sewer were calculated on the basis of 0.163 pound of oxygen per capita 5-day biochemical oxygen demand. The following table compares the population equivalent so obtained with the estimated sewered population.

	Population Equivalent Sewered Area	Estimated Population Sewered Area
Minneapolis	550,000	415,000
St. Paul	430,000	265,000
S. St. Paul & Newport	415,000	4,700

The population equivalent is higher than the estimated population due to industrial wastes. Strong stock yards and packing-house wastes are responsible for the high population equivalent in South St. Paul. From the suspended matter determinations it was calculated that approximately 730,000 cubic yards of wet sludge (95% moisture) is being discharged into the river each year. The bacterial examinations indicated normal conditions and did not indicate the presence of any inhibiting substances which might interfere with biological processes.

The extent of the treatment needed depends upon whether the elimination of nuisance, or the preservation of fish and other aquatic life is desired. To prevent nuisance the treatment indicated would be the equivalent of sedimentation of the entire volume of sewage of the Twin Cities and the sewage and packing plant wastes from South St. Paul plus complete treatment of 10 per cent of the clarified sewage in 1930, with a gradual increase in complete treatment up to 60 per cent in 1970. The

amount of treatment required for the protection of fish life in the river below the Hastings Dam was calculated on the assumption that a minimum of 4.0 p. p. m. of dissolved oxygen would be required in Lake Pepin. On this basis all sewage would have to be clarified and complete treatment would have to be increased from 40 per cent in 1930, to 80 per cent in 1970.

Six plant sites and twenty treatment projects were studied from the standpoint of costs and also the effect on the value and use of the neighboring property. Five construction programs to 1945 were outlined. The treatment project which is recommended by the commission utilizes a system of medium-level interceptors by means of which all of the sewage would be delivered to a site in the vicinity of Pig's Eye Lake for treatment. About 1000 acres of land on the east side of the river, south of St. Paul, are available at this site. This site would be suitable for digestion tanks and drying beds, as a large area of comparatively waste land remote from dwellings is available, which would serve for sludge disposal for many years. This project permits the construction of either an activated sludge plant or a trickling filter type of plant and provides for complete treatment in 1970 exclusive of South St. Paul and Newport. Cost data on these plants are given in the following table.

	Construction Costs			Operating Costs		
Plant	Total	per M. G. of Plant Capacity	Per Capita	Per Annum	per M. G. of D. W. F.	Per Capita per Yr.
Activated sludge	$28,760,000	$128,000	$20.20	$1,220,000	$14.90	$0.86
Trickling filter	37,540,000	168,000	26.40	425,000	5.20	0.30

Of the total cost of construction for either type of plant $13,600,000 is for intercepting sewers and appurtenances. Disregarding first cost this project has advantages over any of the others.

The Commission concludes: (1) That Minneapolis and St. Paul should form a single district for the treatment and disposal of sewage.

(2) That South St. Paul and Newport should be left out of the district at the present but should be permitted to contract with the district for the disposal of their sewage and wastes.

(3) That the project which has been briefly described be adopted, provided equitable financial adjustments can be made.

Pollution of the Mississippi River (143 pages).—This investigation was carried on in 1928, the work being confined to the 60-mile section of the river from Minneapolis to La Crosse. The sources of pollution on the river and all tributaries in this section were investigated. Twenty-four sampling stations were established and samples were collected at intervals of two weeks. The following determinations were made on all samples: temperature, turbidity, total hardness, alkalinity, hydrogen-ion concentration, dissolved oxygen, biochemical oxygen demand, total bacterial count on agar at 37.5° C. after 48 hours, determination of coli-

aerogenes index, enumeration of plankton organisms and enumeration of bottom fauna.

The biochemical oxygen demand data show that the pollution caused by the sewage and industrial wastes of the Twin City area extends into Lake Pepin. Self purification is retarded by the entry of wastes from the cities of Hastings, Red Wing, Winona and La Crosse. Self purification is aided by the waters of the St. Croix and Chippewa Rivers but the other rivers are of little influence. During the summer low-water discharge periods there is an unfavorable oxygen balance in the 30-mile section of the river from the Twin Cities to Hastings.

Below Red Wing the river widens to form Lake Pepin and absorbs sufficient oxygen during periods of open water to satisfy the greater part of the demand. In this section of the river the most critical season is the winter when re-oxygenation of the water is prevented by the covering of ice.

On the basis of the bacteriological results this section of the river may be divided into four zones: a zone of heavy pollution from Minneapolis to the St. Croix River below Hastings, a zone of partial recovery from the St. Croix to Lake Pepin, a zone of more complete recovery in Lake Pepin and a zone of intermittent pollution and recovery below the outlet of Lake Pepin.

The study of the bottom fauna showed that pollutional organisms outnumbered all others from Minneapolis to Hastings, and also the predominance of a few typical types indicated that the bottom associations in this section were all pollutional in character. Cleaner organisms appeared in small numbers below Red Wing and predominated below the outlet at Lake Pepin. The plankton examinations showed a rapid rise in the percentage of pollutional organisms from Minneapolis to Red Wing. Below Lake Pepin the per cent diminishes to a condition equivalent to that at Camden above Minneapolis. The maximum numbers of pollutional organisms occurred at Hastings and Red Wing. There was a striking correlation between the numbers of clean organisms and the dissolved oxygen in the water at the various stations. The studies of the bottom fauna and plankton studies yielded practically identical conclusions with respect to the degree of pollution and stage of recovery.

In the first two zones mentioned above the river is unfit as a source of water supply, for bathing or for boating, and is a potential source of danger from a health standpoint to persons and live stock coming in contact with the water. Nuisances are frequent in both zones. The fish life has been practically exterminated in the first zone and has been restricted in the second zone. The opinion of the authorities is that the pollution of the river should be restricted so that "the public health hazard will be reduced to a minimum, the live stock will not be materially endangered, the present public nuisance will be eliminated and the fish life in the river, at least below the mouth of the St. Croix, will not be jeopardized."